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PRELIMINARY REPORT

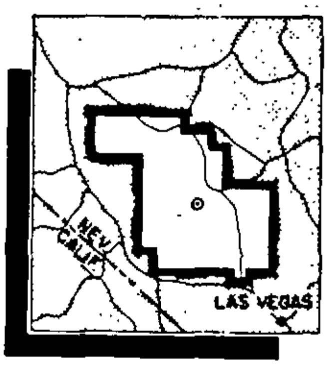
Operation TEAPOT

NEVADA TEST SITE

February — May 1955

Project 39.7

PHYSICAL MEASUREMENT OF NEUTRON AND GAMMA RADIATION DOSE FROM HIGH NEUTRON YIELD WEAPONS AND CORRELATION OF DOSE WITH BIOLOGICAL EFFECT



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CIVIL EFFECTS TEST GROUP

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HCE-950

ITR-1167

This document consists of 106 pages

No. 204 of 270 copies, Series A

Operation Teapot Preliminary Report

Project 39.7

PHYSICAL MEASUREMENT OF NEUTRON AND GAMMA RADIATION DOSE FROM HIGH NEUTRON YIELD WEAPONS AND CORRELATION OF DOSE WITH BIOLOGICAL EFFECT

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Director
Program 39 and Civil Effects Test Group

April 1955

This is a preliminary report based on all data available at the close of the operation. The contents of this report are subject to change upon evaluation for the final report. Conclusions and recommendations drawn, if any, are tentative. The work is reported at this time in order to provide early test results to those concerned with effects of nuclear weapons and to provide for an interchange of information between projects for the preparation of final reports.

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ABSTRACT

Physical measurements of neutron and gamma radiation dose as a function of distance from point of detonation were made of the Wasp, Moth, Hornet, Bee, and Wasp-Prime, shots of Operation Teapot. Neutron dose in rep was calculated from flux measurements with Au, Au-Cd, Np^{237}-B^{10}, Pu^{239}-B^{10}, U^{238}-B^{10} and S detectors. Neutron measurements with tissue-equivalent ionization chambers were also made to test functional characteristics of the ion chambers. Measurement of neutron and gamma radiation dose was made inside and outside 7-inch thick lead hemispheres used in previous tests for exposing mice to neutron radiation. Gamma radiation measurements were also made inside 1/4-inch thick aluminum exposure stations, at various depths in the lead shields and at various heights above and below ground.

Measurements of radiation effect inside 7-inch lead stations and inside 1/4-inch aluminum stations as a function of distance from point of detonation were made also, using CF_1 female mice. Splenic and thymic weight loss 5 days after exposure, total body weight loss 72 hours after exposure, and median survival time were the responses used as biological indicators of radiation effect.

A preliminary summary of the results is as follows:

The neutron foil system gave excellent indirect measurements of neutron dose (in rep) under field conditions.

Over the region of measurement (from 1 to 6 mean free paths), no variation in bomb neutron spectrum as a function of distance was found.

At all distances, the neutron dose (in rep) inside the 7-inch thick lead exposure stations was 1/2 that in air and the primary effect of the lead was the degradation of neutrons with energies above 1.5 mev down into the energy region of 700 kev to 1.5 mev.

The neutron to gamma radiation dose ratios in air were extremely high for the specific weapons considered, and the neutron dose per kiloton was definitely a function of bomb geometry and the presence or absence of boosting.

Perturbations were introduced in the neutron dose by asymmetries in bomb geometry and as a result of shielding by various bomb components, such as the "X-unit".

The chloroform chemical dosimeter with varying concentrations of water in the system was a satisfactory method for the measurement of gamma rays in the presence of neutrons, both in lead and in air, if adequately calibrated and if the neutron sensitivity is satisfactorily evaluated.

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At all distances, the gamma ray dose inside the lead exposure stations was only about 7 per cent of the neutron dose.

The modified NBS film pack was a satisfactory method for the determination of gamma radiation dose in air, if corrections due to thermal and fast neutron effect and other film responses are applied. The same film packet was inadequate, however, for measurement of the gamma ray dose inside the lead hemisphere for those situations in which the thermal neutron flux was high and the total neutron dose in air was 50 per cent or more of the total rep dose delivered.

The tissue-equivalent ionization chamber saturated under field exposure conditions. The tissue-equivalent and graphite CO_2 ion chamber system, in the design used in the present measurements, was inadequate for field measurement of total dose, gamma ray dose, or neutron dose.

Over the dose range of 100 to 1000 rem, the RBE of bomb neutrons averaged 1.7.

Over the dose range of 100 to 1000 rem, the RBE of bomb gamma rays was not significantly different from 1.

The RBE of bomb neutrons appeared to vary slowly as the total dose increased and may be inversely proportional to the dose rate above some limiting value.

Additivity of bomb neutrons and gamma rays appeared to be complete.

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PREFACE

The purpose of this report is to afford preliminary distribution of the data collected by Project 39.7, CETG, on the physical and biological assessment of neutron and gamma radiation doses as a function of distance from point of detonation of the Wasp, Moth, Hornet, Bee, and Wasp-Prime nuclear devices detonated during Operation Teapot.

Primary objectives of the study were the evaluation of certain methods of physical dosimetry of the neutron and gamma ray components of the mixed radiations from an atomic detonation and an evaluation of the perturbation of neutron and gamma radiation doses produced by the 7-inch lead domes used for the exposure of biological materials during past operations.

Those using this report should keep in mind that the information is given in preliminary form, and in some cases without refinement and proper evaluation, in order that the material may be made available in the shortest possible time. Some of the numbers and portions of the discussion and evaluation of data may be changed in the final report.

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ACKNOWLEDGMENTS

The various participants in Project 39.7 wish to acknowledge the whole-hearted support of the CETG Program Director, Mr. Robert L. Corsbie. They also wish to acknowledge the support of the authorities of their respective organizations who sanctioned their taking part in this effort. Obviously, they are indebted to numerous perons who did not participate directly in the operation, but who performed innumerable supporting functions. The Project participants are highly indebted to the Group that operates the Tower Reactor at Oak Ridge and to LASL Group W-2 personnel, who operate the Godiva assembly. These two groups rendered invaluable aid and service during the calibration of many of the methods of physical and biological dosimetry.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

The general objective of Project 39.7 was to correlate by physical and biological means neutron and gamma radiation dose and effect from nuclear devices which, because of design, were expected to yield high ratios of neutron to gamma radiation dose. Two of the weapons on which measurements were made were of the "boosted" and three were of the "non-boosted" types, which provided an opportunity to study the neutron and gamma radiation dose and effect of "boosted" versus "non-boosted" weapons.

A highly important objective of Project 39.7 was a more careful assessment of the magnitude and effect of gamma and neutron radiation doses inside and outside the 7-inch lead hemispherical exposure containers used during Operations Greenhouse, Tumbler-Snapper and Upshot-Knothole for the study of the biological effects of neutrons from nuclear detonations.

Another objective of this Project was the measurement of neutron dose in rep as a function of distance from the point of detonation and comparison of different methods of physical dosimetry of neutrons and gamma rays. A part of this objective also was the measurement of the biological effects of neutrons and neutron plus gamma radiation simultaneously with physical measurement of radiation dose in order to obtain information concerning the relative biological effectiveness of bomb radiations and the additivity of neutrons plus gamma rays.

Other objectives were the collection of additional information on the characteristics and performance of tissue-equivalent ion chambers and chloroform-phase dosimeters under field conditions and to measure gamma radiation dose as a function of height above and below ground.

1.2 BACKGROUND INFORMATION

1.2.1 Physical Measurements

Physical measurements of neutrons and gamma rays as a function of distance from point of detonation have been made at all tests since Operation Sandstone.

Generally, the neutron measurements consisted of flux determinations with gold and sulphur threshold detectors. By using two sets of gold foils, one bare and one covered with cadmium, the difference in activation was used as an index of the total neutron flux below 0.3 ev. The activation of sulphur foils, on the other hand, gave an index of the total neutron flux above 3 mev. These measurements gave no knowledge of the flux of neutrons of intermediate energies, which are responsible for a large portion of the neutron dose, and gave very little knowledge of the neutron spectrum, which is essential for dose calculations. The above measurements were, therefore, not adequate for correlation of physical dose with the biological effects of neutrons.

It was not until Operation Upshot-Knothole in 1953 that specific physical measurements of neutron dose were attempted. During that operation, Hurst et al. (1), attempted to use a fission foil system to measure the neutron flux in broad spectral bands between the energy range of 0.3 ev and 3 mev. From these measurements, it was possible to calculate the neutron dose in rep on the basis of single collision theory. The few results that were obtained indicated that the method had excellent possibilities for field use. In the same operation the first attempt was made also to measure directly the neutron dose in rep by means of the tissue-equivalent ionization chamber designed by Rossi (2).

Using a tissue-equivalent chamber filled with tissue-equivalent gas, it is possible to determine the total radiation dose, in rep, delivered to tissue by neutrons plus gamma rays. The simultaneous use of a graphite chamber filled with CO_2 permits the determination of the gamma ray dose alone. By subtracting the dose due to gamma rays alone from the total radiation dose measured by the tissue-equivalent chamber, it is possible to obtain directly the radiation dose in rep delivered by the neutrons. Measurement of neutron dose by this method is obviously independent of neutron energy and spectral distribution. The results obtained during Operation Upshot-Knothole were few and inconsistent and indicated that a variety of problems was involved. These problems included possible saturation effects of high radiation dose rates, the reliability of the chambers under field conditions, the general effects of radiation on the insulators and cases of the chambers, the possible sensitivity of the graphite chamber to neutrons, the effect of polarity of the chamber, and the problem of adequate calibration of both the graphite and tissue-equivalent chambers against suitable sources of radiation.

Also, in Operation Upshot-Knothole, attempts were made to measure neutrons by measuring the change in conductivity of the semiconductor, germanium. These measurements, of course, do not measure rep or flux directly but depend on calibration against a suitable radiation source. Studies so far indicate a consistency in response which, if the detectors are calibrated against suitable neutron sources, will permit a physical measurement of energy flux.

Physical measurements of gamma radiation dose have been made during every test program since Operation Trinity in 1945. Film badges have been used almost exclusively for these measurements. Since a film badge only measures indirectly the radiation dose in roentgens, the applicability of the method depends upon the sensitivity of the film to other radiations and upon the calibration of the film against a suitable

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source of radiation. A film packet for measuring gamma radiation dose from nuclear detonations was developed by the Bureau of Standards for use during Operation Greenhouse. This same film packet has been used at all subsequent tests as an index of gamma radiation dose versus distance. The packet was developed with the purpose of eliminating the variation in film sensitivity with gamma ray energy between 110 kev and 10 mev.

It is known that the packet is sensitive to thermal neutrons and experiments at Los Alamos indicated that 4×10^9 thermal neutrons per square centimeter gave a density reading which was equivalent to that produced by 1 r of Co^{60} gamma rays. The sensitivity of the packet to fast neutrons has not been thoroughly studied but some pertinent data on fast neutron response will be given in the final report of this project.

1.2.2 Biological Measurements

Biological systems have been used to measure both neutron and gamma radiation dose versus distance from nuclear detonations. Biological measurements were first conducted at Operation Greenhouse in 1951 (3). During this operation, a variety of biological systems was used to study radiation effect. Only one system, however, proved sufficiently practical in the field to be employed in more than one subsequent test. This particular system is based on the quantitative relationship between radiation dose and the weight loss of the spleen and thymus of the mouse 5 days after exposure. The biological response was calibrated against known doses of hard X-ray irradiation, and the results obtained with neutrons and gamma rays in the field were interpreted in terms of the calibration curve to determine the radiation dose in rem. The method is applicable over the dose range of 100 to 1000 rem. It was used to measure neutron and gamma ray dose as a function of distance during Operation Greenhouse and to measure neutron dose on subsequent shots during Operations Tumbler-Snapper (4) and Upshot-Knothole (5). The same mouse exposure containers, with minor modifications, were used during all operations and for the present experiments.

Laboratory experiments conducted at Los Alamos (6) using multi-kilocurie Ba-La gamma radiation sources have indicated that median survival time may be a suitable biological method for measuring radiation dose in the field over the dose range of 10,000 to 150,000 rem. Over this range, the dose response relationship may be represented by an expression of the type

$$\log Y = a - bX$$

where Y is the median survival time and X is the radiation dose in rem. In this dose range, the median survival time is probably a measure of the direct effect of radiation on the central nervous system. Present studies constitute the first attempt to apply this biological response to the measurement of neutrons and gamma rays from a nuclear detonation.

Another simple quantitative biological method of measuring radiation effect is whole-body weight loss. Laboratory studies at Los Alamos (7) have shown that whole body weight loss of mice 72 hours after

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exposure is linearly related to radiation dose over the range of 100 to 1200 rem when the weight loss is expressed as per cent of the body weight of unirradiated controls. This method was used in the present studies to supplement radiation dose measurements by the spleen-thymus weight loss method.

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CHAPTER 2

EXPERIMENTAL METHODS

2.1 PARTICIPATION

Project 39.7 participation was confined to five shots of the Operation Teapot series. The experiments were planned on the bases of the particular devices to be detonated and their predicted yields. The shots chosen for the program were selected on the basis of (a) predicted high neutron to gamma ray flux, (b) the presence of minimal shielding and perturbing materials in the vicinity of the device, and (c) applicability of the results to previous detonations and to planned stockpile items.

The five devices selected, their characteristics and the conditions of detonation were as follows:

(1) The Wasp, a non-boosted device, yield 1.2 KT, 800-foot air-burst at a position 426 feet West, 36 feet North, and 39 feet low with respect to the predicted point of detonation;

(2) The Moth, a non-boosted device, yield 2.5 KT, detonated on a 300-foot tower;

(3) The Hornet, a boosted device, yield 3.6 KT, detonated on a 300-foot tower;

(4) The Bee, a boosted device, yield 8.1 KT, detonated on a 500-foot tower; and

(5) The Wasp-Prime, a non-boosted device, yield 3.2 KT, 800-foot air-burst at a position 62 feet West, 95 feet North, and 61 feet low with respect to the predicted point of detonation.

The various studies carried out under Project 39.7 may be divided into physical and biological measurements. The physical measurements carried out were as follows:

(1) Measurement of neutron dose (in rep) inside and outside 7-inch lead exposure stations used for the animal studies, as a function of distance from point of detonation, using the Hurst fission foil and threshold detector systems.

(2) Measurement of neutron and gamma radiation dose inside 7-inch thick lead shields as a function of distance from detonation, using the Rossi tissue-equivalent and graphite ionization chamber method, primarily to determine the effect of various ion chamber characteristics on their performance.

(3) Determination of response of germanium semi-conductors inside and outside the 7-inch lead exposure stations as a function of distance from point of detonation. The details of the results of this study are reported separately as a part of Project 39.5 (report ITR-1170).

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(4) Measurement of gamma radiation dose inside and outside 7-inch lead, animal exposure stations and inside 1/4-inch thick aluminum animal exposure stations versus distance from point of detonation, using EG&G film packs and chloroform-phase dosimeters.

(5) Measurement of gamma radiation dose as a function of distance above and below ground and distance from point of detonation, using EG&G film packs.

The biological measurements carried out on each shot were as follows:

(1) Measurement of biological effect of neutrons inside 7-inch lead exposure shields as a function of distance from point of detonation, using weight loss of spleen and thymus, whole body weight loss, and median survival time of CF_1 female mice.

(2) Measurement of biological effect of neutron plus gamma radiation inside 1/4-inch aluminum exposure stations as a function of distance from point of detonation, using weight loss of spleen and thymus, whole body weight loss and median survival time of CF_1 female mice.

2.2 METHODS OF PHYSICAL MEASUREMENT

2.2.1 Neutrons

The threshold detector method of measuring neutron dose in rep is based on the determination of neutron flux in specific regions of the energy spectrum by taking advantage of energy intervals over which the foils have flat responses. From the flux measurements and the average values for rep per neutron per square centimeter, calculated from single collision theory, it is possible to calculate the neutron dose in rep delivered to tissue by a known flux.

The foil systems used to measure neutron dose inside and outside the lead exposure stations as a function of distance from point of detonation consisted of Au, Au + Cd, Pu^{239}, Np^{237}, and U^{238} surrounded with 2 cm of B^{10} and S. The purpose of surrounding the three fission foils with 2 cm of B^{10} is to eliminate the high Pu fission cross-section for thermal neutrons and to eliminate resonances in the epi-thermal region. Under these conditions, the total neutron fluxes above the effective thresholds of the detectors may be measured after a single calibration of the Au and Pu foils against a known thermal neutron flux and calibration of the S pellets against a known flux of 14 mev neutrons from the DT reaction produced with the Cockcroft-Walton Accelerator. The foil system used in the present study gave the total neutron fluxes in the following energy intervals:

Au - (Au + Cd)	= total neutron flux below 0.3 ev.
Pu^{239} - Np^{237}	= total flux between 100 ev and 0.75 mev.
Np^{237} - U	= total flux between 0.75 and 1.5 mev.
U^{238} - S	= total flux between 1.5 and 2.35 mev.
S	= total flux above 3 mev.

The neutron dose in each energy interval was calculated from the total number of neutrons in each interval and from the average rep per neutron per square centimeter. The sum of the doses in the various

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intervals gave the total neutron dose in rep.

Threshold detector measurements of neutron dose were made at 10 different distances from point of detonation on each of the shots. Measurements were made both inside the 7-inch lead stations used for animal exposures, and in the open.

The measurement of neutron dose with tissue-equivalent ionization chambers is based on the determination of the ions produced by the neutrons in a chamber constructed of material having essentially the chemical composition of tissue and filled with tissue-equivalent gas. Theoretically, such a chamber should provide a direct determination of tissue neutron dose in rep regardless of the spectrum of the incident neutrons. Obviously, the tissue-equivalent chamber also responds to gamma radiation, and in a mixed radiation field an independent measurement of gamma dose must be made and subtracted from the total in order to obtain the dose due to neutrons alone.

Graphite chambers filled with CO_2, which theoretically should be insensitive to neutrons, were used to measure the gamma radiation dose. Dummy tissue-equivalent chambers were also used to test insulator effects and characteristics. The chambers were of two ranges, one reading a maximum of 200 rep and the other a maximum of 2000 rep. Placement in the field was predicated on the basis of these ranges. Since the chambers had not been extensively field tested, the primary experiments in the field were planned to test chamber characteristics and adequacy of design. Since the question of saturation and ion recombination had never been satisfactorily solved for the dose rates involved, 24 chambers of the various types charged to different collecting voltages were utilized at each location. Originally, eight locations were planned for each shot. The actual numbers used, however, varied because of change in experimental design in the field and failure and discard of a number of the chambers.

Cassen et al. (8) have shown that the conductance characteristics of the semi-conductor, germanium, are altered by exposure to fast neutrons and that the degree of alteration is proportional to neutron dose. The conductance of germanium is essentially unaltered by gamma rays; therefore, germanium detectors that have been adequately calibrated against a known fast neutron flux provide a method of measuring neutrons in the presence of gamma radiation. Calibrated, single-crystal germanium fast neutron detectors were placed in a number of the exposure containers on each detonation to measure fast neutrons versus distance.

2.2.2 Gamma Rays

Two different methods were used to measure gamma radiation dose versus distance on all detonations.

The film packet, as developed by the National Bureau of Standards and modified by EG&G, was used to measure gamma radiation versus distance under four different conditions. Measurements were made on each of the five shots inside 15 of the 7-inch lead exposure stations, in 15 stations of 1/4-inch aluminum, and at 10 different locations in the open. The packs were also used to measure gamma radiation dose at various distances above and below ground at 10 different distances from point of detonation.

In order to partially eliminate and further evaluate the thermal

neutron response of the films, some packets were wrapped in lithium metal which decreased the thermal neutron flux reaching the film by factors of about 4 to 8. The film response to fast neutrons was accepted but was checked and partially evaluated during calibration experiments at LASL using the Godiva assembly. All film packs were furnished, developed and read by EG&G.

The so-called half-phase chloroform chemical dosimeters were used also to measure gamma radiation dose as a function of distance from the point of detonation on each of the five shots. Gamma radiation measurements were made inside the 7-inch lead and the 1/4-inch aluminum exposure stations which constituted all of the positions at which animals were placed.

The phase chemical dosimeters are composed of a chloroform-conductivity water system adjusted to pH 1. Under the influence of ionizing radiations, a chain reaction is initiated which results in rather sensitive changes in the pH of the system. Determination of the magnitude of pH change by either colorimetric or titrimetric methods gives a measure of the radiation dose.

By changing the amount of water in the system, it is possible to vary the response to neutrons. As the water content of the dosimeter is decreased, its neutron response decreases. By using the so-called half-phase system (that system in which the chloroform is essentially anhydrous), it is possible to practically eliminate the fast neutron response and measure gamma radiation dose in the presence of neutrons.

By using half-phase, single-phase and two-phase systems in combination, it is possible to make a differential measurement of neutron and gamma radiation dose. Experiments have shown that chemical dosimeters of this type give some response to thermal neutrons and are energy-dependent to gamma rays below 80 kev. The chemical dosimeters were, therefore, wrapped in 0.5 mm of lead and varying thicknesses of lithium metal to eliminate gamma rays having energies of 80 kev or less and to lessen their response to thermal neutrons.

2.3 METHODS OF BIOLOGICAL MEASUREMENT

Mice were used to measure the biological effect of neutrons and neutrons plus gamma rays on each of the five shots as a function of distance from the point of detonation.

By placing animals in 1/4-inch aluminum stations and in 7-inch lead-shielded stations, it was possible to get a differential biological effect in terms of rem due to neutrons plus gamma rays, and neutrons and gamma rays alone. In this way, questions of additivity of mixed radiations could be studied.

From the biological measurements made in these studies, rem dose versus distance curves could be developed. When these curves were compared with rep versus distance curves established by the physical dosimeters previously mentioned, it was possible to determine an RBE figure for the prompt radiations from nuclear detonations.

Three different responses were used as indicators of biological effect, namely, spleen-thymus weight loss, median survival time and total body weight loss. All mice used to measure biological effects were commercially procurred CF_1 females. The animals used for

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spleen-thymus weight loss determinations were from 8 to 10 weeks of age at time of exposure. Those used for median survival time studies were 14 to 16 weeks of age. The animals were flown from LASL to the Nevada facility 3 to 4 days prior to participation. On D-2 the mice of each age group were randomized separately on the basis of random number tables and weighed and randomly assigned to exposure groups. The animals were loaded into their respective cages and placed in the exposure units in the field as late as possible in the evening of D-1. Adequate non-stressed controls were kept at the housing facility and non-irradiated environmentally-stressed controls were placed in exposure units set up outside. As soon after shot time as possible, the exposed animals and the stressed controls were recovered and returned to the housing facility where they were given water and Purina Laboratory chow *ad libitum* during the post-exposure period.

2.3.1 Spleen-Thymus Weight Loss

Spleen-thymus weight loss was used to measure biological effect over the dose range of 100 to 1000 rem. The method was essentially as follows:

Groups of 20 mice each, assembled into groups and assigned to exposure positions on the basis of a system of random numbers, were exposed to neutrons inside 7-inch lead exposure stations and to neutrons plus gamma rays inside 1/4-inch aluminum hemispheres. The exposed animals and groups of unirradiated but stressed controls were killed at 120 hours after exposure. The spleens and thymuses were dissected out and the wet weights of the spleens determined immediately to the nearest milligram. The thymuses were placed in 10 per cent formalin for 24 hours to facilitate removal of excess fat and connective tissue. Following removal of the adherent tissues, each thymus was blotted dry and weighed. The mean per cent organ weight loss for each group was determined by comparison with the mean splenic and thymic weights of the non-irradiated controls that were stressed, caged and killed in an essentially identical manner. In determinations of the mean weights of the various groups, weights falling outside 2.4 standard deviations were discarded and new means calculated. The neutron and neutron plus gamma radiation doses (in rem) received by the various groups of animals were calculated from a dose-response regression equation that was established on the same mouse strain by exposing appropriately large numbers of animals to graded doses of 250 KVP X rays after appropriate environmental stressing.

2.3.2 Median Survival Time

Median survival time of mice was used at each of the detonations to measure biological effect of neutrons and neutrons plus gamma rays in the supra-lethal dose range. The biological effect of massive doses of radiation from nuclear detonations has never been measured before and may be of interest in certain defensive and tactical bombing situations.

The median survival time of CF_1 female mice, following radiation doses above 10,000 rem, decreases exponentially with increasing dose. This relationship may be represented by an expression of the type

$$\log Y = a - bX$$

[redacted]

where Y is the median survival time and X is the radiation dose. The expression was shown to hold between doses of 10,000 and 150,000 rem, although a relatively small discontinuity in the curve between 80,000 and 120,000 rem has been indicated. This deviation, however, does not significantly lessen the value of the relationship as a quantitative method of radiation effect in the supra-lethal range. In this dose range the median survival time is probably a measure of the direct effect of radiation on the central nervous system. The method is not applicable in the range of 1000 to 10,000 r, over which the survival time is approximately 3.5 days and is independent of radiation dose. Below 1000 rem, the median survival time is also exponential with dose, and was used as an index of radiation effect in this range in conjunction with spleen and thymus weight loss, in order to get portions of the total median survival time curve at both ends of the flat response region.

Groups composed of 20 randomly selected mice each, were exposed at various distances from the point of detonation of each of the five devices. Groups were exposed inside 7-inch lead shields and inside 1/4-inch aluminum hemispheres for neutron and neutron plus gamma radiation effects, respectively.

After recovery, the mice were returned to their living quarters and the time of death of the animals in each group observed. The median survival time of each group was determined by plotting probit of per cent mortality against log of time after exposure. The median survival time was the time corresponding to probit 5 (50 per cent mortality). The dose of neutrons and neutrons plus gamma rays (in rem) for each group was determined from a dose-response regression line established with Ba-La gamma radiation delivered at 4000-6000 rep per minute.

2.3.3 Total Body Weight Loss

Total body weight loss of mice is a very simple indicator of radiation effect and because of its simplicity was used to supplement biological effect measurements made by the spleen-thymus weight loss method. The basis of the method is a linear relationship between weight loss of irradiated animals, expressed as per cent of the body weight of unexposed controls, and the radiation dose over the dose range of 100-1200 rem. More recent studies have indicated a possibility of extending the weight loss method to include a dose range of 100-10,000 rem. Total body weight loss determinations were made on animals exposed both to neutrons and neutrons plus gamma rays. The same groups of animals, used also for the spleen-thymus weight loss determinations, were carefully weighed prior to exposure and used for the weight loss determinations. Seventy-two hours after exposure, they were weighed again. The irradiated groups and the stressed, unirradiated control animals chosen at random from the same population were given water and food ad libitum during the post-exposure period. The rem dose of neutrons and neutrons plus gamma rays received by each group was determined from the per cent weight loss and a dose-response regression line established by irradiating stressed animals of the same strain, sex and age with graded doses of 250 KVP X rays.

[redacted]

Fifteen of the Series "b" stations were placed on each of the five shots, and their locations, in terms of slant range from point of detonation and distance from Ground Zero for each of the detonations, are given in Table 2.1. An example of the Series "b" station is shown in Figure 2.2.

The Series "c" stations used for the exposure of various types of dosimeters in the open consisted of the "goal post" arrangement used by LASL Group J-12 on past operations for the exposure of neutron detectors and other measuring devices. The various materials exposed in the open were placed in suitable containers to protect them from blast and the containers were fastened to the crossbar of the goal posts with U-bolts. An example of the Series "c" station is shown in Figure 2.3. Ten Series "c" stations were placed on each of the five shots. The locations of these stations with respect to Ground Zero and slant range from each detonation are given in Table 2.1.

The Series "d" stations were used exclusively for the exposure of the tissue-equivalent, the dummy and the graphite ionization chambers. These stations consisted of 7-inch thick lead domes identical to those used for the Series "a" stations, with the exception that no ventilation was provided. No extraneous measuring equipment or materials, which could perturb or otherwise alter the neutron flux, were placed in the Series "d" stations. The ionization chambers were racked in 2 banks in such a manner that self-shielding was eliminated and the active volumes of the chambers were perpendicular to a line through the point of detonation. Eight of the Series "d" stations were placed on each of the five shots. They were not all used, however, on each shot because of field changes in the experimental plan. The locations of these stations with respect to Ground Zero and slant range from each detonation are given in Table 2.1.

An additional exposure container was located adjacent to the 10 Series "c" stations for the purpose of studying gamma radiation dose as a function of distance above and below ground level. This exposure container consisted of a 3-inch steel pipe, 6 feet long, 3 feet of which were buried below the ground. The upper end of the pipe was closed with a steel cap. EG&G film packs were suspended on a string fastened to the cap in a manner such that the packs were positioned at +3, +2, +1, 0, -1 and -2 feet from ground level. The locations of these exposure units on each of the shots were the same as those given for the Series "a" stations, the locations of which are given in Table 2.1. Figure 2.4 shows the exposure pipe and the arrangement of the film packs before lowering into position.

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2.4 STATION PLACEMENT AND FIELD EXPOSURE METHODS

The nuclear devices selected for Project 39.7 participation were detonated in two different areas. In order to save work and time, a system of station placement was used which made it possible to utilize the stations on two different shots in the same area without relocating them. The station positions, therefore, were not in line but were essentially in arcs between two detonation points at varying distances from each. However, because of additional construction in the Hornet tower cab that would have perturbed the radiation dose at the locations in the center of the arc, it was necessary to relocate a number of stations in a straight line in another sector for that particular shot.

The distances selected for placement of the various measuring systems on each of the five shots are given in Table 2.1. The station locations depended upon predictions from data obtained from previous detonations in other operations and upon the predicted yields of the devices in question.

As different distances and different numbers of stations were required for each type of measurement, the stations were arranged in series as to type and designated Series "a" through "d". Series "a" stations in all cases consisted of 15 7-inch thick lead hemispherical shields. Series "b" stations consisted of 15 aluminum hemisphere units. Series "c" stations consisted of 10 "goal post" units used to expose the various dosimeters in the open and Series "d" stations consisted of 8 lead hemisphere units used for the tissue-equivalent ion chamber studies. Thus, the general field placement consisted of four series or types of stations arranged in four arcs on different radii between two detonation points. The materials placed in each series of stations are shown also in Table 2.1.

It was expected that the arc arrangement of stations would indicate any differences in symmetry which might have occurred due to unforeseen perturbing factors around the bomb assemblies.

As mentioned previously, the exposure units used in these studies were essentially the same or similar to those used on previous operations. The Series "a" stations used for the exposure of animals to neutrons were the same as those used for the same purpose during Operations Greenhouse, Tumbler-Snapper and Upshot-Knothole. These stations consisted of lead domes 28 inches in diameter with walls 7 inches thick. These domes were provided with a 4-inch access port on one side and were mounted above an appropriate ventilating system. The ventilating system was slightly modified for this operation. Fifteen of the Series "a" stations were placed on each of the five shots. The locations of these stations in terms of distance from Ground Zero and slant distance from point of detonation for the Wasp, Moth, Hornet, Bee, and Wasp-Prime are given in Table 2.1. An example of the Series "a" station is shown in Figure 2.1.

The Series "b" stations which were used to expose animals to neutrons plus gamma rays were the same stations used for similar exposures during Operation Greenhouse. They consisted of 16-inch diameter aluminum hemispheres 1/4-inch thick and were mounted above an appropriate ventilating system buried in the ground. Again, the ventilating system was slightly modified from that used during Operation Greenhouse.

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CHAPTER 3

CALIBRATION OF METHODS

Attempts were made to calibrate all physical and biological methods used in Project 39.7 prior to the operation. It was not always possible to calibrate all of the methods to the extent of complete satisfaction. In other cases, it was not possible to completely analyze the data prior to test time. For the above reasons, it was not possible to report pre-test calibration data in this report. These data, however, will be given in the final document.

The general methods of calibration of both physical and biological methods are presented below.

3.1 PHYSICAL METHODS

3.1.1 Neutrons

The neutron threshold detector system has been calibrated a number of times in the past by Hurst et al. Calibration has consisted of checking the foil systems against theoretical single-collision dose calculations and against the Hurst Proportional Neutron Counter using the ORNL Cyclotron, the ORNL Tower Reactor facility and the LASL Godiva assembly as neutron sources.

The tissue-equivalent ionization chamber method and the particular chambers used in Project 39.7 were calibrated for gamma ray response using the LASL 250 KVP G. E. Maxitron X-ray machine and the 250 KVP Picker Industrial unit. During the field tests the chambers were again calibrated at UCLA and afterwards again at Columbia. The chambers were calibrated for neutron response, using the LASL Godiva assembly. Tests for saturation effect were conducted by operating the assembly at different power settings and under critical burst conditions. In the latter case, the entire neutron dose was delivered over a period of only 45 μsec. The various chambers were also tested for leakage and insulator effects. No measurements were made of the response of the chambers to thermal neutrons.

The germanium single-crystal fast neutron detectors were calibrated for fast neutron response against the University of California Cyclotron and a few were tested with fission neutrons using the Los Alamos Godiva assembly. Numerous tests for gamma ray response of these

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detectors were conducted using conventional X-ray machines.

The chloroform-phase dosimeter system, in which differential measurements made with half-phase, one-phase and two-phase dosimeters provide an estimation of neutron dose, was tested in preliminary fashion, both at the Tower Reactor facility at Oak Ridge and the Godiva assembly at Los Alamos. These tests indicated that the differential phase system may give neutron dose readings that are about 30 per cent low when compared with the Hurst foil method.

3.1.2 Gamma Rays

The principal gamma ray dosimeters used in Project 39.7 were the EG&G film packs and the half-phase chloroform chemical dosimeter.

The EG&G film packs were calibrated against the Los Alamos 250 KVP X-ray machines. The various film types used in the film packs were also checked for thermal neutron sensitivity in the thermal column of the Los Alamos Homogenous Reactor. Both the film packs and the film types were checked for fission neutron response using the Los Alamos Godiva assembly. Calibration curves for dose versus film density using Co^{60} gamma radiation and the 10 mev Betatron were established by the Bureau of Standards in Washington.

Over the past several months the half-phase chloroform dosimeter has been calibrated repeatedly for its response to X and gamma rays, and just prior to use in the field it was checked for fission neutron response both at the Oak Ridge Tower Reactor facility and the Los Alamos Godiva assembly. It has not been tested adequately for its response to thermal neutrons.

The graphite chambers used as a part of the tissue-equivalent ion chamber system also provided a potential measure of gamma radiation dose. These chambers were calibrated for gamma ray response using the Los Alamos X-ray machines and also tested for their response to fission neutrons using the Godiva assembly. They have not been adequately calibrated for thermal and fast neutron sensitivity and pre-test calibration experiments definitely indicate a neutron response.

3.2 BIOLOGICAL METHODS

The same biological test systems, namely, spleen-thymus weight loss, total body weight loss, and median survival time, were used to measure the biological effects from both neutron and neutron plus gamma radiation.

3.2.1 Spleen-Thymus Weight Loss

The spleen-thymus weight loss response of CF_1 female mice has been calibrated many times at LASL against X and gamma rays and thermal and fission neutrons. It is standard practice, however, to establish the base line response of the experimental animal population just prior to application, using animals stressed under essentially the same conditions encountered in the field. Prior to test, base line response curves were established on CF_1 female mice 7 to 9 weeks of age that had been placed outdoors in the animal exposure containers and allowed to

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remain overnight under temperature conditions comparable to those expected in the field. After the animals had remained in the exposure containers overnight, they were exposed to graded doses of 250 KVP X rays ranging from 100 to 1000 r. Five days after exposure, the weight loss of their spleens and thymuses was determined to provide the base line dose response curve. This base line response curve served as an adequate pre-test calibration of the spleen-thymus weight loss method.

3.2.2 Total Body Weight Loss

The total body weight loss response curve was calibrated and a base line was established with the same mice used for the spleen-thymus weight loss method. The animals were carefully weighed prior to being placed outdoors in the animal exposure containers. Seventy-two hours after exposure to radiation, the animals were again weighed and their total body weight loss compared to that of a group of stressed but unirradiated controls. These data were used to establish the base line response curve and provided adequate calibration of the method. Post-test experiments have indicated a possibility of extending the weight loss method to include the dose range of 100 to 10,000 r. Using 250 KVP X rays, calibration curves were extended to include this entire range.

3.2.3 Median Survival Time

A base line for the median survival time response was established at Los Alamos by exposing animals to massive doses of gamma radiation delivered at dose rates of 4,000 to 6,000 rep per minute from a multi-kilocurie Ba-La radiation source. The base line response curve, however, was not established on animals stressed by placement in the animal exposure containers overnight. It was shown, however, that mice that were stressed in the containers prior to exposure to massive doses of 250 KVP X rays showed median survival times that were quite in keeping with that expected from the Ba-La gamma radiation dose response curve of unstressed animals. Prior to the final report, a calibration curve for fission neutrons in the high dose range will be established using Godiva as the neutron source.

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CHAPTER 4

RESULTS

4.1 PHYSICAL MEASUREMENTS

4.1.1 Neutrons

The neutron flux measurements determined by the threshold detectors and fission foils in 7 inches of lead and in air are summarized in Tables 4.1, 4.2, 4.3, 4.4, and 4.5 for the Wasp, Moth, Hornet, Bee, and Wasp-Prime, respectively. These are preliminary values and the missing data have not as yet been calculated. These data give fluxes in the energy intervals of <0.3 ev (thermal), >100 ev, >750 kev, >1.5 mev, and >2.5 mev in air and inside the Series "a" lead exposure stations. From these data the neutron dose, in rep, inside and outside the 7-inch lead shields as a function of distance was calculated for each of the five devices. The results of these dose calculations are summarized in Table 4.6. The data showing the neutron flux inside and outside the lead exposure containers for each of the five shots are plotted in Figures 4.1 through 4.10. The data for the slow neutron flux inside and outside the lead stations are shown in Figures 4.11 and 4.12.

The results of the neutron dose measurements inside the lead and aluminum exposure stations using the chloroform-phase chemical dosimeters are shown in Tables 4.7 through 4.11, for the Wasp, Moth, Hornet, Bee, and Wasp-Prime, consecutively. These results are listed in the fourth column (1-phase neutron rep) for both the Series "a" lead-shielded stations and Series "b" aluminum stations. These results are "as read" determinations and have not been increased upward by 30 per cent, as was indicated necessary by the calibration runs between the chemical dosimeter system and the fission foil systems. The results are shown graphically in Figures 4.13 through 4.17 by the curves labeled "n inside lead" and "n in aluminum".

The fast neutron measurements collected with the single-crystal germanium detectors inside and outside the Series "a" lead-shielded stations were made in collaboration with Project 39.5. The primary data are presented in the preliminary report, ITR-1170.

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4.1.2 Gamma Rays

The results of the gamma ray measurements made with the chloroform chemical dosimeter system are shown in Tables 4.7 through 4.11. These results are in the columns labeled "1/2-phase gamma rep" and "2-phase gamma rep". The 1/2-phase system is the basic method by which the gamma dose is determined. The final result of the 2-phase system depends upon the solution of simultaneous equations developed from 1-phase and 2-phase initial numbers. The 1/2-phase results are included in Figures 4.13 through 4.17 and are shown by the curves labeled "γ in lead" and "γ in aluminum".

The results of the film badge measurements made at various distances from the detonation points for each of the five devices are given in Tables 4.12 through 4.16. The results are given in terms of roentgens read on the films. The roentgen number was determined by comparison with calibration curves found for the various emulsions by the use of a Co^{60} source and a 10 mev Betatron. The calibrations were made at the National Bureau of Standards. Data are shown from measurements at Series "a", "b", and "c" station locations. In certain cases the packets were wrapped with lithium, in order to get an indication of the thermal neutron response of the film. The data of the aluminum-shielded stations and air measurements are plotted in Figures 4.18 and 4.19.

In no case have corrections been applied to these results, in order to account for thermal neutron sensitivity (approximately 4×10^9 neutrons per square centimeter per density change equal to 1 roentgen), fast neutron sensitivity (about 2.5 per cent per rep of fast neutrons), and others, including activation and consequent exposure of the packet between time of recovery and time of development, and light response of the film due to scintillations produced in a high dose rate field of heavy particles. The results found inside the hemispherical lead shields are not amenable to plotting at the present time.

The film badge measurements made inside the 3-inch pipes at various distances above and below ground were not available at the time of issuance of the preliminary report.

4.1.3 Saturation Measurements

The results of the measurements on ionization chamber saturation are shown in Tables 4.17 through 4.21. The tables indicate the total dose in rep as measured by the high dose (2000 rep) or low dose (200 rep) tissue-equivalent or graphite chambers and the charging voltage and direction of each. No dummy chamber results are given and various corrections have not been applied. These are raw data determined by multiplication of the total discharge by the rep per unit discharge found on the latest X-ray calibration of the chamber.

4.2 BIOLOGICAL MEASUREMENTS

4.2.1 Spleen-Thymus Weight Change

The results of the spleen and thymus weight determinations are shown in Tables 4.22 through 4.26. The results are listed for both the

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Series "a" lead-shielded stations and Series "b" aluminum stations. The weight values are listed as per cent of control weight and were determined by comparison with unirradiated control animals which were placed in an identical exposure unit at the time of field placement and recovered at the same time as the irradiated animals. Thus, the exposure conditions were essentially reproduced to eliminate environmental effects on the response.

Not all stations for any one detonation were activated for measurement of this response. The range of the method is roughly limited by the 100 and 1000 rem levels and restricts the area of measurement. Values less than 100 rem are estimates only. On the Wasp shot, extreme weather conditions and a 5-hour delay caused the loss of several stations as noted in Table 4.22.

The rem doses shown in the tables are not final, but are for purposes of the preliminary report only. These values were determined by comparison with 250 KVP X-ray control runs made at Los Alamos in 1949, 1950, 1951, and 1954, with the same strain, sex and comparable age groups of animals. The 1954 runs were made after exposure to similar environmental conditions in a unit identical to those used in the field. The result is computed on the basis of comparison to the response found after a known dose of X radiation.

The data are plotted in Figures 4.20 and 4.21, in which each point is the average of both the spleen and thymus values. The curves shown have been adjusted parallel by F-testing the results of different detonations.

4.2.2 Median Survival Time

Median survival time data are also given in Tables 4.22 through 4.26. These results are on the basis of the time of survival (measured from time of exposure) of 50 per cent of the exposed group. In certain instances, no median survival time is given and the notation "dead-blast" is written in. In these cases, all the animals were dead on recovery; the external appearance indicated blast effects and subsequent autopsy indicated blast death. The rem values given in the tables were determined by comparing the median survival times with those obtained from calibration data using Ba La gamma radiation. As with the splenic-thymic response, calibration measurements were made under similar environmental and exposure conditions insofar as possible.

4.2.3 Body Weight Loss

The body weight loss data are listed in Tables 4.22 through 4.26 also. The per cent weight loss is the algebraic sum of the control weight change and the exposed animal weight change in terms of percentage of the pre-exposure animal weight. In certain instances, weight changes are left blank because some animals with very low exposures actually gained more weight than did the controls. The final weight was measured at 72 hours post-exposure. No rem values are listed in the preliminary report because laboratory work is now under way to attempt to extend the method and give a reasonable result in terms of rem in the region in which the median survival time plateaus (between 1200 and 10,000 rem).

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CHAPTER 5

DISCUSSION

5.1 PHYSICAL MEASUREMENTS

5.1.1 Neutrons

The neutron measurements made with the various threshold detector systems yield information of importance in an understanding of the physics of bomb neutron radiation, which had only been estimated up to the present.

If the thermal neutrons are first considered, it will be noted that single curves are used to represent the thermal flux, both in lead and in air. This result was determined by statistical means and indicates that thermal neutrons absorbed by lead are replaced by higher energy neutrons thermalized by elastic scattering in the lead wall. The apparent parallelism of the curves for all detonations was a result derived from an analysis of variance of the data in the region over which the flux curve is linear. Although changes in air density were not considered in this analysis, the data still did not indicate significant differences in slope. The mean free path (1/e degradation in flux) is 180 yards over the linear portion of the curves.

The information derived from an extrapolation of the curves to Zero distance is shown in Table 5.1. The rep constant was determined from the theoretical value 4.45×10^{-11} rep per neutron per square centimeter, which agrees well with the measured value of 4.2×10^{-11} rep per neutron per square centimeter (9). It will be shown later that the dosage contribution of thermal neutrons is insignificant under these experimental conditions. The flux per kiloton yield is of interest from the point of view of bomb physics. The difference of no more than a few centimeters of high explosive is sufficient to change the thermal neutron yield radically, as the two devices with more high-explosive shielding are lower in apparent thermal source strength than any of the others. The differences in thermal yield within a group (boosted or non-boosted of the same geometry) can best be explained on the basis of information obtained elsewhere (10), which indicates a dependence on various bomb parameters including yield, mass of components, compression at detonation time, etc.

The fission foil and sulfur detector results are extremely important from both biological and physical points of view. First, it is apparent that over the ranges of measurement (which extend approximately from one mean free path from the source to several mean free paths), the flux times distance squared versus distance curves are parallel for a particular detonation. This result indicates that there is no spectral change for neutrons in the various energy regions measured.

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The invariance of the spectrum under any particular set of conditions has particular advantages, as will be noted later.

The threshold detector measurements were used to determine the total numbers of neutrons in various energy ranges and, consequently, dosage in terms of rep by consideration of the single-collision theory of neutron energy deposition in tissue. The dosage conversion factors are given in Table 5.2. In Table 5.3 are given the results of the application of these conversion factors to the data. This table shows the per cent of total neutrons in each energy interval and the per cent of the total dose delivered. Generally, about 50 per cent of the total fast neutrons are of energies below 700 kev. The majority of remaining neutrons are of energies between 700 kev and 2.5 mev in any case. As would be expected, boosting only increases the proportion of high energy neutrons by adding the 14 mev component. The number is still a small proportion of the total. The interposition of the lead shield, also, has the expected effect. It degrades neutrons of energies greater than 1.5 mev into the 700 kev to 1.5 mev region. This degradation is primarily by inelastic scattering. As the neutrons enter the region of elastic scattering, relatively little further degradation occurs. This result was predicted a number of years ago (11) from data collected during Operation Greenhouse. The per cent of the total dose contributed by the various spectral regions is a variant which depends on the neutron behavior listed above. As has been predicted (11), by far the largest proportion of the total dose is given by neutrons in the energy region 700 kev to 2.5 mev. Thus, results obtained by others could not be used to determine biological effectiveness, as has been attempted elsewhere (4), since physical measuring devices for the most important energy regions were not used. The proportion of dose due to thermal neutrons has not been included in Table 5.3. The total thermal contribution is never greater than 1-2 per cent of the total dose and may be neglected.

Spectral invariance with distance is important, both from the aspect of analyzing these data and for future experimental work. The results indicate that a single detector may be used (under these experimental conditions) for most stations with only minimal full coverage to determine the neutron characteristics of a particular design of bomb. Also, the result will be of importance in the re-analysis of old information from other detonations (4, 5, 11).

The formulae for neutron dose versus distance determined from the foil data are shown in Table 5.4. The ratios of dose in lead to dose in air are given. The result indicates a decrease by a factor of 2, due to the 7-inch lead hemispheres. A decrease of this order of magnitude had been predicted several years ago (11). It will be noted that the mean free paths given in the formulae are not constant from detonation to detonation. No attempt has been made to apply air density corrections to these formulae, but it is doubtful that the variance in the data is small enough to make the air density corrections significant. The rep doses given in Table 5.4 have been derived by the application of theory to experiment. Calibration of the system against the proportional counter system of measuring neutron dose was carried out using the Godiva assembly at Los Alamos. Agreement was within 1 per cent.

A rough estimation of the neutron rep per kiloton yield of the various detonations (neglecting mean free path variations) shows an increase as the amount of high-explosive shielding decreases and with boosting.

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The highest yield is found with the Bee device. This [redacted] boosted bomb gave over 40 times the neutron rep per kiloton when compared to Greenhouse Dog (11), [redacted] Figures 4.5 and 4.6, (neutron threshold detector data, Hornet), show that the three closest points for fast neutrons from the Hornet shot are uniformly low. This result indicates perturbation of the neutron flux from the bomb. Perturbations due to the bomb assembly were first noted in a previous test (12). Such variations can only be determined if the detectors are located on different radii from the detonation point and thus "see" obvious asymmetries. It is probable, in this case, that the perturbed fluxes were due to shielding of the detectors by the X-unit. It is evident that previous results should be re-investigated to determine the possibility of perturbations.

The neutron measurements made with the 1-phase chloroform chemical dosimeter give dose data quite comparable with the foil results. The formulae for dose versus distance relationship are shown in Table 5.5. For the five detonations, the ratio of dose inside lead to that inside aluminum is again approximately 0.5, although the scatter of the data is greater. The mean free paths are very close to those given by the foils and differences are probably insignificant. In all cases, the neutron dose in rep indicated by the dosimeters averages 20 per cent less than the foil results. This result is about 10 per cent more than that found in comparisons of the dosimeter with the foils using the Godiva assembly as a source of fission neutrons. The difference is suggested as being due to decreased spectral sensitivity of the system at neutron energies below a few hundred kilovolts. Conversely, the decreased discrepancy noted between the Godiva spectrum and the bomb spectrum may be due to a highly increased thermal component with reasonable penetration of the lithium shield around the dosimeters. The apparent decreased mean free path occurring in all cases could, also, be explained on the basis of thermal neutron sensitivity.

5.1.2 Gamma Rays

Film methods have primarily been used to measure gamma ray dose from atomic weapons. For this series of experiments it was decided to use film, but other methods were investigated. This was done because of the anomalous results given by film at Upshot-Knothole Operation, particularly in connection with the measurements on the Gun shot. Those results indicated a much higher gamma flux inside the lead shields than could be estimated on any basis. At that time, it was suggested that the response of the NBS packet to thermal and fast neutrons caused the excess blackening of the film. Therefore, with the extremely high neutron flux encountered (never occurring before under these experimental conditions) the film method was not a good measure of gamma dose. Also, it was impossible to obtain the exact calibration of the neutron response of the film before the series began. Chemical dosimetry was suggested as an alternative method and, fortunately, a well-devised and well-calibrated system was available. This was the chloroform system in which the neutron response could be varied by the relative chloroform-to-water concentration in the dosimeter solution.

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The so-called 1/2-phase system, in which the water concentration was minimal, was used as a measure of gamma dose alone inside the lead hemispheres. This method was initially calibrated at the Tower shielding facility at ORNL, using a standard lead hemisphere unit, and gave a good measure of the gamma inside the lead, when compared with other methods. The results for these particular detonations are as consistent as would be expected from the calibration runs. The results indicate that the primary source of gamma rays inside the lead shields is interaction of fast neutrons with the lead and materials in the shields. This is apparent because the slope of the inside lead gamma dose curve is the same as the neutron flux curves. The slope is much steeper than the gamma ray slope in air. Secondly, the results consistently show that the gamma dose inside lead is only 7 per cent of the neutron dose inside lead (when compared to foil dose measurements). A result of this order has been predicted on the basis of theoretical estimates (11) and on the basis of the ORNL calibration.

The gamma measurements made inside the aluminum hemispheres with the 1/2-phase system are summarized in Table 5.6. These formulae were developed from the results at levels above 100 rep. The system becomes insensitive at lower levels. The measured mean free paths are comparable with those measured at previous detonations at N. T. S. If the data are put on a rep per kiloton basis (neglecting air density or mean free path variations), the results fall into two groups. [redacted] There are two possible conclusions. These are (1) a significant portion of the gamma ray dose is due to neutron interaction in air, and (2) the system is sensitive enough to thermal neutrons so that the apparent increased gamma dose is due to an actual increased thermal flux. Until the thermal neutron sensitivity of the system is checked absolutely (estimates of a 15 per cent response have been made), the result will be assumed due to the second mechanism. A check of all detonations up to this operation indicate that gamma ray production at large distances from the main source by local neutron action in air is not important. This conclusion is at variance with estimates of others.

The measurements with the 2-phase system have only been included in tabular form (Tables 4.7 through 4.11). These data show discrepancies which increase as the total doses of both neutrons and gamma rays increase. Since the 2-phase result depends upon the mathematical analyses of simultaneous equations and errors may be additive, the system must be further checked before final conclusions may be reached.

It is impossible at the present time to reach any conclusions on the film badge results inside the lead hemispheres. If analysis of the data presented in the tables is attempted, the results are most unsatisfactory. The resultant curves have no physical meaning. It is apparent that corrections must be applied. Some of these are, fast neutron response, thermal neutron response (immediate blackening), activation by captured neutrons and consequent exposure, and possible light response by high dose rate scintillation produced in the packet.

The film measurements in the aluminum hemispheres and "in air" are much more reasonable even with no attempts at correction of the raw data. In this case, the corrections that must be applied are a small

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percentage of the total gamma effect (except at distances close to the point of detonation) and, in fact, decrease with increasing distance to become almost negligible. Generally, the resultant curves agree fairly well with those obtained from the 1/2-phase chemical dosimeter system.

5.1.3 Ion Chamber Studies

The primary purpose of these studies was to investigate the behavior of tissue-equivalent ionization chambers when exposed to doses up to several thousand rep. In particular, it was decided to obtain concrete information on saturation and effect of the radiation on the insulators.

About 200 chambers were exposed at varying distances from Ground Zero at the Wasp, Moth, Hornet, Bee and Wasp-Prime shots. In order to test saturation, the chambers were kept at four different voltages, i.e., 200, 400, 600, and 730 volts. In addition, the chambers were constructed with two gap sizes, 15 mils and 150 mils. Chambers were operated at either polarity and were either tissue-equivalent, filled with tissue-equivalent gas; graphite, filled with CO_2; or dummies, i.e., chambers having no significant ionizable volume. The chambers were originally calibrated against a 250 KVP X-ray source at Los Alamos. At that time, it was found that the readings of "dummy" chambers were of the order of 10 per cent of the readings of ionization chambers. However, after the first exposure (Wasp), it became evident that the "dummy" readings were not only very much larger, but in addition, showed a high degree of erratic response. Similarly, the readings of ionization chambers at the same station varied by as much as $\pm$ 50 per cent and more. It was decided that this effect was at least in part due to a parasitic volume arising from thermal contraction of ionization chamber parts due to the considerable temperature variations encountered. As a result, data at the inner stations, where the narrow gap chambers were employed, have been discarded entirely. The data at the outer stations suggest that saturation had indeed been attained, at least beyond a collecting voltage of 400 volts. However, even these figures were so erratic that this conclusion had to be drawn on substantially statistical basis. Following Moth, the chambers were re-designed, leading to a modified structure having only one insulator and in addition, clamps were provided to apply a steady pressure to all chambers in a given station. It was found impossible to calibrate these new chambers prior to Hornet, although a series of attempts to do so were made at a cobalt source at Mercury. The data obtained at Hornet were rather erratic, which was later found to be due, at least in part, to radiation leakage of the insulators that had been exposed to many thousands of roentgens during the Co^{60} tests. However, immediately following Hornet, the chambers were calibrated at an X-ray machine at UCLA. When the result of the calibrations was applied to the data from Hornet, it became evident that there was still a rather erratic chamber response and that the insulator effects of these chambers, when exposed to atomic weapons, are far more severe than in the case of X-ray exposures. In addition, it became evident that there are at least two effects on the insulation, one that reverses with applied polarity, and one that does not. The net effect on "dummy" chambers was found to be as great as 30 per cent, as compared with the

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total reading of corresponding ionization chambers operated at positive polarity. When the "dummy" readings were subtracted from the readings of corresponding ionization chambers, it was found that most of the tissue-equivalent chambers at a given station read within about 30 per cent of each other, but that the spread in graphite chambers was considerably greater, or about 60 per cent.

As a result of the experience with Hornet, it was decided to put all chambers in both Bee and Wasp-Prime into only four stations, using the low sensitivity, i.e., small gap chambers, at the two stations closest to Ground Zero and to place the high sensitivity, i.e., wide gap chambers, at the next two stations. This permitted insertion of several chambers at the same voltage and polarity and of the same type in a given station and improved the statistical validity of the data obtained considerably. Since, in addition, the doses registered at Bee were considerably higher, substantial deflections were obtained and after application of the "dummy" corrections, there was good agreement among the narrow gap tissue-equivalent ionization chambers. On the other hand, the wide gap chambers clearly exhibited lack of saturation. In addition, it was found possible to subject the two components of the insulator effect to an analysis which is consistent with the assumption that the non-reversing effects are independent of applied voltage at any given station and may be considered as a net transfer of positive charge to the central electrode structure. This effect appears to be roughly proportional to the dose received. To our knowledge, this effect has not been observed before and its exact nature must remain a matter of speculation until future experiments can be performed. It is evident, however, in retrospect, that a similar smaller effect was observed when dummies were exposed to gamma radiation, except that in this case the sign was reversed. When the chambers are exposed to X radiation, the effect is still less, but of the same polarity as in the case of gamma radiation.

The reversing part of the insulator effect is similar to the one of ohmic leakage, being proportional to applied voltage and roughly proportional to dose. This effect has been observed in insulators before.

Following Bee, the data obtained at Wasp-Prime were substantially similar, although the scatter of data was somewhat wider which is, at least in part, due to the fact that the chambers had developed substantial leakage which appears to be ordinary surface leakage rather than being radiation-induced.

Following the test series, the chambers have been subjected to extensive recalibration and final numerical data will have to await a detailed computation based on these calibrations.

Throughout these experiments the scatter in the data obtained with the graphite chambers was considerably larger than the one observed with tissue-equivalent chambers. Consequently, an assessment of a relative amount of neutron and gamma radiation received in the hemispheres is going to be difficult.

The preliminary conclusion drawn, as a result of the work performed to date, indicates that measurement of doses in excess of 1000 rep is difficult when performed with chambers of the type employed, and cannot be performed unless dummies are exposed simultaneously and

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the readings of these are applied as a very substantial correction.

5.2 BIOLOGICAL MEASUREMENTS

5.2.1 Spleen-Thymus Response

Weight loss of the spleen and/or thymus of mice has been used as a biological dosimeter in connection with all test biological experimentation to date. The method has been facile enough to be used for field work, in that it does not depend absolutely on exact predictions of yield or other bomb parameters. The range of the method is such that the dose curve for acute response can be covered from 100 to 1000 rem--sublethal to supralethal doses. As would be expected, the variances of biological methods are certainly more extreme than for a physical measuring system.

The data shown in Figures 4.20 and 4.21 all use the average rem given by both the spleen and thymus response at a particular distance from a particular detonation. The curves are derived from all the data and the common slopes seen are a result of the analytical method used. The formulae used for the construction of the curves are shown in Table 5.7. These data show that the order of ascending biological dose is the same as would be expected from the physical dosimetric measurements. In both exposure situations, however, the mean free path for 1/e degradation in dose is shorter than the corresponding physical measurement. The 210-yard value given for the lead stations is less than the 220 to 250-yard values shown by the foil measurements. The 240-yard value for aluminum is far shorter than the 300 to 375-yard numbers given for gamma rays. The biological dose inside the aluminum stations, which is composed of both a neutron and a gamma ray component, further emphasizes the importance of the neutron contribution to total bomb radiation dose, even in the range of 100 to 1000 rem.

5.2.2 Median Survival Time

The results of the median survival time measurements, in which the estimated rem values were determined by comparison with calibration curves developed in the laboratory, have not been plotted over distance ranges. They will, however, be utilized in the estimation of effectiveness of the radiations. The method was used to get an idea of biological dose at levels which had never been obtained in field testing. The information may be useful to correlate with physical dosimetry important to weapons designed for specific purposes, such as: anti-aircraft use and for use against targets where shielding negates both blast and thermal effects. Many of the determined points, unfortunately, fall within the region in which the median survival time plateaus at about 3.5 days and can only be used in possible extrapolation from both ends of the curve or as checkpoints on another biological system. Because of the obvious complexities involved, interpretation of the results will not be attempted until the final report.

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5.2.3 Body Weight Loss

Body weight loss in mice was measured as it is hoped that this simple system may give results which will both extend and correlate with organ weight loss and median survival time. The original work in the laboratory indicated that the method had a probable upper dose limit of 1250 to 2500 rem. Work now in progress indicates that the method may be extended to about 10,000 rem which, if true, will prove to be an important correlative to the median survival time results which give doses on the plateau of the response curve. Estimates of rem will be given in the final report.

5.3 COMPARISON OF PHYSICAL AND BIOLOGICAL RESULTS

Adequate physical measurements of radiation dose as made in this series of experiments allow the determination of the biological effectiveness of nuclear radiations from atomic weapons. Attempts at such determinations were made previously but the results depended on assumptions which were not always valid. The present experiments make it possible to compare biological and physical data and arrive at conclusions which, even in preliminary form, give information of value in the analysis of the radiation capabilities of fission weapons and permit a more exact interpretation of past biological studies.

The physical dose data show conclusively that the total dose in rep inside the lead hemispheres is made up of neutron dose primarily, with only about 7 per cent of gamma dose contamination. Since the gamma dose is due to neutron interaction in the lead and components inside the hemisphere, the total dose is increased by a constant small amount at any distance of measurement. This small percentage will be neglected in the biological-physical comparison. Also, it has been shown that the leakage spectrum causing the biological response is spread over a wide energy range with most of the dose being due to fast neutrons of energies below 1.5 mev.

If the dose region covered by the spleen-thymus response is considered, the relative biological effectiveness of the bomb neutron flux may be determined by finding the rem dose to rep dose ratio of each individual point. The resulting points are shown in Figure 5.1. The slope of this curve is the relative biological effectiveness of the bomb neutron radiation and gives a value of 1.7 for this response. The largest and smallest values found are 2.1 and 1.3. This result agrees very well with laboratory determinations made with another fission neutron source, the Godiva reactor, which gave an RBE of about 1.8. The result does not agree with estimates of others, which varied from 5 to 10, but in which the physical dosimetry was non-existent or inadequate.

The data from the median survival time study cannot be considered as simply as the spleen-thymus results. If the results beyond the 3.5 day plateau region in the median survival curve are considered, it will be noted that the rem to rep ratio is not constant, but decreases with increasing dose. In fact, even at levels of 10,000 rem, the ratio is not 1.7 but only about 1.2. At higher rep doses, the ratio continues to decrease until in some cases, it approaches 0.6.

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Only one explanation of this effect of decreased RBE with dose (for the biological effect considered) is apparent at the moment. It is possible that a saturation effect (similar to ion chamber saturation) may have occurred in tissue, and ion recombination has effectively lowered the biological dose. As a large proportion of the total neutron dose is delivered within milliseconds (so that the dose rate may be as high as 10^6 rep per second or more), and since the specific ionization of the proton recoil is high, saturation may have occurred. A more accurate determination of rem dose in the plateau region of median survival time using body weight loss as an index of effect may aid in the completion of the response curve. Qualitatively, it should be noted that observation of the acute symptoms of high total dose exposure did not appear to be lessened at the high dose rates attained in these experiments.

In order to estimate the biological effectiveness of the bomb gamma radiation from the data collected in the aluminum hemisphere stations, it is necessary to subtract the neutron portion of the biological dose from the total. If the value of 1.7 for the neutron RBE is used, the RBE of the gamma ray dose is found to be about 0.8 on the basis of the spleen-thymus response. This value is in reasonable agreement with that found at Operation Greenhouse (11), using the same biological system. No consideration has been given to the rep per kiloton difference mentioned earlier, which may make the given gamma readings [redacted] high. If the gamma dose is decreased in the final analysis, the error in the RBE will be reduced and it will approach 1.0. There is no indication in the results that additivity of the neutron and gamma radiation is incomplete or varies over the range of the data. The apparent complete additivity is consistent with findings in this laboratory, but may be fortuitous in that the neutron to gamma radiation dose ratio (somewhat greater than 1) is relatively constant over the entire range studied.

The median survival time data in the aluminum hemispheres for neutron plus gamma radiation show the same decreasing rem to rep ratio as shown in the lead stations for neutrons alone. Thus, the RBE again appears to decrease with increasing dose and/or dose rate.

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CHAPTER 6

SUMMARY AND CONCLUSIONS

In summary, it may be stated that the general objectives of the experiments were attained. A small amount of biological data was lost, primarily from environmental stresses, including blast effects on equipment at extremely high overpressures. Because of the complexity of the problems involved, it has been possible to give only a very superficial interpretation of the biological data in the preliminary report.

The preliminary conclusions that may be drawn from both the physical and biological studies conducted as Project 39.7, Operation Teapot, are as follows:

6.1 PHYSICAL DOSE STUDIES

a. Over the region of measurement, no variation in neutron spectrum was found.

b. The neutron dose (in rep) inside the 7-inch thick lead exposure stations is 1/2 that in air and the primary effect of the lead is to degrade the neutrons with energies above 1.5 mev down into the energy region of 700 kev to 1.5 mev.

c. The gamma ray dose inside the lead stations is only 7-10 per cent of the neutron dose.

d. The neutron dose to gamma dose ratios in air are extremely high for the specific weapons considered and the neutron dose per kiloton is an important function of bomb geometry and the presence or absence of boosting.

e. Perturbations are introduced in neutron dose by asymmetries in geometry and resultant shielding by various components such as the X-unit.

f. The chloroform chemical dosimeter with varying concentrations of water in the system is a satisfactory method for the measurement of gamma rays in the presence of neutrons, if adequately calibrated and if the neutron sensitivity is satisfactorily evaluated.

g. The modified NBS film packet is a satisfactory method for determination of gamma dose in air, if corrections due to thermal neutron effect, fast neutron effect and other film responses are applied.

h. The same film packet is inadequate for measurement of gamma ray dose inside the lead hemispheres for situations in which the thermal

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neutron flux is high and the total neutron dose in air is 50 per cent or more of the total rep dose.

i. The tissue-equivalent ionization chamber saturates under field exposure conditions. The tissue-equivalent and graphite CO_2 ion chamber system, with present designs, is inadequate for field measurement of total dose, gamma dose or neutron dose.

j. The foil system, including fission foils, is an excellent indirect method for the measurement of neutron dose under field conditions.

6.2 BIOLOGICAL DOSE STUDIES

a. Over the range 100 to 1000 rem, the RBE of bomb neutrons averages 1.7.

b. Over the range 100 to 1000 rem, the RBE of bomb gamma rays approaches 0.8 to 1.0.

c. The RBE of bomb neutrons varies slowly as the total dose increases and is probably inversely proportional to the dose rate above a limiting rate.

d. Additivity of bomb neutrons and gamma rays is probably complete.

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REFERENCES

1. Hurst, G. S., Harter, J. A., Hensley, P. N., Mills, W. A., and Ritchie, R. H., "Neutron Flux and Tissue Dose Studies with Fission Threshold Detectors". ORNL-1671 (1954)

2. Failla, G., and Rossi, H. H., "Annual Report on Research Project". Radiological Research Lab., Columbia University. NYO-4008 (June, 1952)

3. LeRoy, George, et al., "Control Studies Performed in the United States and at Eniwetok", Parts I, II, IV, and VI. Operation Greenhouse Scientific Director's Report Annex 2.2. WT-18 (1951)

4. Carter, R. E., et al., "The Biological Effectiveness of Neutron Radiation from Nuclear Weapons". Operation Snapper, Project 4.3. WT-528 (1952)

5. Carter, R. E., et al., "The Biological Effects of Neutrons". Operation Upshot-Knothole, Nevada Proving Grounds, Project 4.8. WT-757 (1953)

6. Langham, W. H., et al., "Studies of the Effects of Massive, Rapid Doses of Gamma Rays on Mammals". LA-1643 (1954)

7. Woodward, K. T., and Rothermel, S. M., Los Alamos Scientific Laboratory, unpublished studies (1954)

8. Cassen, B., et al., "Measurement of Fast Neutrons by Effects on Semiconductors". Operation Upshot-Knothole. WT-803 (1953)

9. Brennan, J. T., Harris, P. S., Carter, R. E., Langham, W. H., "The Biological Effectiveness of Thermal Neutrons on Mice", II. Nucleonics, 12, No. 4, 31 (1954)

10. Cowan, C. L., "Experimental Neutron Measurements". Operation Buster. WT-416 (1952)

11. Brennan, J. T., et al., "The Biological Effectiveness of Neutron Radiation from an Atomic Bomb". WT-43, Sect. 2, 43 (1951)

12. Cowan, C. L., "External Neutron Measurements". Operation Snapper. WT-555 (1952)

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TABLE 2.1 - Locations of Series "a", "b", "c"* and "d" Stations and Participation

Station Number	Materials Exposed	Wasp Ground Dist. (yds.)	Wasp Slant Dist. (yds.)	Moth Ground Dist. (yds.)	Moth Slant Dist. (yds.)	Hornet Ground Dist. (yds.)	Hornet Slant Dist. (yds.)	Bee Ground Dist. (yds.)	Bee Slant Dist. (yds.)	Wasp-Prime Ground Dist. (yds.)	Wasp-Prime Slant Dist. (yds.)
1a	Mice (for neutrons)	100	310	235	255	1245	1245	1540	1550	100	280
2a	Threshold Detectors	250	390	290	305	1180	1180	1480	1490	250	375
3a	Germanium Detectors	320	440	360	375	1120	1120	1420	1430	320	430
4a	Film Packs	390	495	440	450	1070	1070	1370	1380	390	485
5a	Chemical Dosimeters	460	640	520	530	1020	1020	1320	1330	460	550
6a		580	760	630	640	970	975	1260	1270	580	650
7a		700	875	750	755	920	925	1210	1220	700	760
8a		820	985	870	875	870	875	1150	1160	820	865
9a		870	1015	920	925	750	755	1030	1040	870	910
10a		930	1070	970	975	630	640	910	925	930	960
11a		980	1100	1020	1020	520	530	790	805	980	995
12a		1040	1150	1070	1070	440	450	710	730	1040	1060
13a		1090	1190	1120	1120	360	375	620	645	1090	1110
14a		1140	1225	1180	1180	290	305	540	570	1140	1155
15a		1200	1270	1245	1245	235	255	460	490	1200	1205
1b	Mice (for gamma + neutrons)	100	310	260	280	1370	1370	1800	1810	100	280
2b	Film Packs	260	400	330	345	1300	1300	1720	1730	260	380
3b	Chemical Dosimeters	360	475	410	420	1240	1240	1650	1660	360	460
4b		430	530	490	500	1180	1180	1580	1590	430	520
5b		510	645	550	560	1110	1110	1500	1510	510	600
6b		640	810	680	685	1050	1050	1420	1430	640	710
7b		780	950	800	805	990	995	1350	1360	780	835
8b		900	1065	940	945	940	945	1300	1310	900	945
9b		960	1115	990	995	800	805	1140	1150	960	995
10b		1020	1160	1050	1050	680	685	1000	1015	1020	1045
11b		1080	1205	1110	1110	550	560	880	895	1080	1100
12b		1150	1260	1180	1180	490	500	780	795	1150	1160
13b		1210	1305	1240	1240	410	420	690	710	1210	1225
14b		1280	1360	1300	1300	330	345	600	685	1280	1280
15b		1340	1405	1370	1370	260	280	520	550	1340	1335
1c*	Threshold Detectors	100	310	235	255	235	255	1540	1550	100	280
2c	Germanium Detectors	220	370	350	365	490	500	1420	1430	220	350
3c	Film Packs	340	515	470	480	1070	1070	1300	1310	340	445
4c	Film Packs above and	460	650	590	600	1370	1370	1180	1190	460	535
5c	below ground	580	755	710	715			1060	1070	580	640
6c		700	855	830	835			940	955	700	740
7c		820	955	950	955			820	835	820	845
8c		940	1060	1070	1070			700	720	940	965
9c		1060	1155	1190	1190			580	605	1060	1075
10c		1180	1250	1310	1310			460	490	1180	1185
1d	Tissue Equivalent	600	780	660	670			1700	1710	500	575
2d	Chambers	700	850	760	765	1300	1300	1600	1610	700	780
3d	Graphite Chambers	800	970	860	865	1200	1200	1500	1510	800	860
4d	Dummy Chambers	935	1100	1000	1000	1100	1100	1370	1380	935	980
5d		1021	1180	1100	1100	1000	1000	1265	1275	100	280
6d		1107	1245	1200	1200	860	865	1066	1075	250	375
7d		1200	1325	1300	1300	760	765	947	960	100	280
8d		1295	1400	1400	1400	660	670	829	845	250	375
1x*						250	270				
2x						350	365				
3x						470	480				
4x						590	600				
5x						710	715				
6x						830	835				
7x						950	955				
8x						1090	1090				
9x						1210	1210				
10x						1330	1330				

* The "x" stations are relocated "c" stations, relocated to avoid perturbation of radiations by added construction in the Hornet tower cab.

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TABLE 4.1 - Results of Neutron Threshold Detector Measurements in 7 Inches of Lead and in Air (Wasp)

Station No.	Slant Dist. (Yds.)	Measured Flux (n/cm^2)				
		Thermal	Pu	Np	U	S
1a (lead)	310	2.20×10^{13}	1.09×10^{13}	5.73×10^{12}	1.83×10^{12}	1.68×10^{11}
2a	390	4.44×10^{12}	5.00×10^{12}	2.39×10^{12}	8.50×10^{11}	7.01×10^{10}
3a	440	2.62×10^{12}	3.00×10^{12}	1.67×10^{12}	5.04×10^{11}	4.31×10^{10}
4a	495	1.92×10^{12}	2.04×10^{12}	1.08×10^{12}	3.11×10^{11}	3.08×10^{10}
5a	640	3.10×10^{11}	1.54×10^{12}	2.99×10^{11}	1.07×10^{11}	1.03×10^{10}
6a	760	1.20×10^{11}	2.98×10^{11}	1.69×10^{11}	5.87×10^{10}	4.43×10^{9}
7a	875	7.36×10^{10}	1.44×10^{11}	6.28×10^{10}	2.41×10^{10}	1.93×10^{9}
8a	985	4.54×10^{10}	7.22×10^{10}	---	1.47×10^{10}	8.50×10^{8}
9a	1015	2.51×10^{10}	3.82×10^{10}	2.60×10^{10}	8.60×10^{9}	---
10a	1070	3.50×10^{10}	4.38×10^{10}	---	6.52×10^{9}	---
11a	1100	3.38×10^{10}	3.64×10^{10}	---	6.35×10^{9}	---
12a	1150	1.70×10^{10}	2.73×10^{10}	1.25×10^{10}	4.16×10^{9}	---
13a	1190	1.68×10^{10}	2.11×10^{10}	---	3.28×10^{9}	---
14a	1225	8.62×10^{9}	1.80×10^{10}	---	2.76×10^{9}	---
15a	1270	8.16×10^{9}	1.37×10^{10}	1.02×10^{10}	2.32×10^{9}	---
1c (air)	310	1.82×10^{13}	1.98×10^{13}	1.10×10^{13}	4.93×10^{12}	1.01×10^{12}
2c	370	9.20×10^{12}	1.09×10^{13}	---	---	5.53×10^{11}
3c	515	2.28×10^{12}	3.20×10^{12}	1.71×10^{12}	8.50×10^{11}	2.02×10^{11}
4c	650	4.76×10^{11}	1.17×10^{12}	---	---	6.90×10^{10}
5c	755	2.12×10^{11}	6.31×10^{11}	---	---	3.51×10^{10}
6c	855	9.20×10^{10}	3.29×10^{11}	1.59×10^{11}	8.75×10^{10}	1.69×10^{10}
7c	955	5.52×10^{10}	1.64×10^{11}	---	---	8.82×10^{9}
8c	1060	3.45×10^{10}	8.93×10^{10}	---	2.18×10^{10}	5.11×10^{9}
9c	1155	1.71×10^{10}	5.07×10^{10}	---	---	2.61×10^{9}
10c	1250	1.09×10^{10}	2.95×10^{10}	1.23×10^{10}	6.8×10^{9}	1.55×10^{9}

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TABLE 4.2 - Results of Neutron Threshold Detector Measurements in 7 Inches of Lead and in Air (Moth)

Station No.	Slant Dist. (Yds.)	Measured Flux (n/cm^2)				
		Thermal	Pu	Np	U	S
1a (lead)	255	6.53×10^{13}	1.98×10^{13}	1.03×10^{13}	2.71×10^{12}	2.47×10^{11}
2a	305	2.84×10^{13}	9.64×10^{12}	---	1.36×10^{12}	9.81×10^{10}
3a	375	Samples Lost	6.00×10^{12}	2.20×10^{12}	8.07×10^{11}	4.86×10^{10}
4a	450	2.29×10^{12}	2.47×10^{12}	---	5.15×10^{11}	2.95×10^{10}
5a	550	8.90×10^{11}	1.33×10^{12}	6.14×10^{11}	1.96×10^{11}	1.40×10^{10}
6a	640	3.37×10^{11}	6.53×10^{11}	---	9.78×10^{10}	8.72×10^{9}
7a	755	2.39×10^{11}	2.54×10^{11}	1.17×10^{11}	3.71×10^{10}	3.16×10^{9}
8a	875	9.60×10^{10}	1.07×10^{11}	---	1.62×10^{10}	1.14×10^{9}
9a	925	7.40×10^{10}	7.98×10^{10}	2.83×10^{10}	1.07×10^{10}	1.11×10^{9}
10a	975	4.76×10^{10}	5.42×10^{10}	---	7.36×10^{9}	1.32×10^{9}
11a	1020	3.19×10^{10}	4.84×10^{10}	1.48×10^{10}	6.30×10^{9}	1.05×10^{9}
12a	1070	1.61×10^{10}	3.85×10^{10}	---	4.10×10^{9}	9.84×10^{8}
13a	1120	1.53×10^{10}	2.37×10^{10}	8.01×10^{9}	3.98×10^{9}	6.25×10^{8}
14a	1180	1.03×10^{10}	1.58×10^{10}	---	2.27×10^{9}	2.78×10^{8}
15a	1245	8.40×10^{9}	1.34×10^{10}	4.11×10^{9}	2.24×10^{9}	2.31×10^{8}
1c (air)	255	6.58×10^{13}	4.10×10^{13}	4.73×10^{13}	9.11×10^{12}	1.59×10^{12}
2c	365	1.66×10^{13}	1.15×10^{13}	---	3.04×10^{12}	5.20×10^{11}
3c	480	4.68×10^{12}	3.69×10^{12}	1.89×10^{12}	9.15×10^{11}	1.80×10^{11}
4c	600	6.90×10^{11}	1.60×10^{12}	---	3.96×10^{11}	7.66×10^{10}
5c	715	2.45×10^{11}	7.46×10^{11}	---	1.65×10^{11}	3.92×10^{10}
6c	835	5.90×10^{10}	3.00×10^{11}	1.43×10^{11}	8.56×10^{10}	1.50×10^{10}
7c	955	4.60×10^{10}	1.37×10^{11}	--	3.15×10^{10}	8.19×10^{9}
8c	1070	1.86×10^{10}	6.67×10^{10}	---	1.62×10^{10}	3.42×10^{9}
9c	1190	1.22×10^{10}	3.04×10^{10}	---	8.20×10^{9}	1.58×10^{9}
10c	1310	1.35×10^{10}	1.90×10^{10}	7.79×10^{9}	4.66×10^{9}	1.38×10^{9}

[redacted]

TABLE 4.3 - Results of Neutron Threshold Detector Measurements
in 7 Inches of Lead and in Air (Hornet)

Station No.	Slant Dist.(Yds.)	Measured Flux (n/cm^2)				
		Thermal	Pu	Np	U	S
15a (lead)	255	4.69×10^{13}	3.30×10^{13}	1.28×10^{13}	4.17×10^{12}	7.46×10^{11}
14a	305	1.80×10^{13}	1.52×10^{13}	7.33×10^{12}	2.30×10^{12}	2.90×10^{11}
13a	375	1.76×10^{13}	8.96×10^{12}	3.82×10^{12}	1.15×10^{12}	1.55×10^{11}
12a	450	3.72×10^{12}	5.93×10^{12}	2.68×10^{12}	1.11×10^{12}	1.52×10^{11}
11a*	550	2.28×10^{12}	3.16×10^{12}	1.50×10^{12}	6.43×10^{11}	8.14×10^{10}
10a*	640	9.20×10^{11}	1.42×10^{12}	6.63×10^{11}	2.80×10^{11}	3.49×10^{10}
9a *	755	5.44×10^{11}	6.47×10^{11}	2.88×10^{11}	1.22×10^{11}	1.52×10^{10}
8a *	875	1.61×10^{11}	2.69×10^{11}	1.30×10^{11}	5.34×10^{10}	6.72×10^{9}
7a *	925	1.70×10^{11}	1.94×10^{11}	9.11×10^{10}	3.73×10^{10}	4.91×10^{9}
6a *	975	8.30×10^{10}	1.37×10^{11}	6.41×10^{10}	2.73×10^{10}	3.44×10^{9}
5a *	1020	5.49×10^{10}	1.02×10^{11}	4.81×10^{10}	2.02×10^{10}	2.79×10^{9}
4a	1070	4.49×10^{10}	7.37×10^{10}	3.51×10^{10}	1.49×10^{10}	2.10×10^{9}
3a	1120	3.90×10^{10}	5.36×10^{10}	2.56×10^{10}	1.06×10^{10}	1.52×10^{9}
2a	1180	2.77×10^{10}	3.60×10^{10}	1.73×10^{10}	7.27×10^{9}	1.08×10^{9}
1a	1245	1.74×10^{10}	2.39×10^{10}	1.16×10^{10}	4.84×10^{9}	7.10×10^{8}
1x (air)	270	5.00×10^{13}	6.62×10^{13}	2.76×10^{13}	2.51×10^{13}	5.38×10^{12}
2x	365	---	2.46×10^{13}	6.83×10^{12}	9.09×10^{12}	2.08×10^{12}
3x	480	4.07×10^{12}	8.66×10^{12}	3.81×10^{12}	3.12×10^{12}	7.60×10^{11}
4x	600	1.18×10^{12}	3.41×10^{12}	1.51×10^{12}	1.22×10^{12}	3.02×10^{11}
5x	715	4.61×10^{11}	1.46×10^{12}	6.71×10^{11}	5.06×10^{11}	1.27×10^{11}
6x	835	2.03×10^{11}	6.44×10^{11}	3.08×10^{11}	2.20×10^{11}	5.72×10^{10}
7x	955	9.70×10^{10}	2.96×10^{11}	1.45×10^{11}	9.87×10^{10}	2.63×10^{10}
8x	1090	4.10×10^{10}	1.29×10^{11}	6.55×10^{10}	4.16×10^{10}	1.16×10^{10}
9x	1210	1.69×10^{10}	6.44×10^{10}	3.29×10^{10}	1.99×10^{10}	5.68×10^{9}
10x	1330	9.60×10^{11}	3.16×10^{10}	1.69×10^{10}	9.72×10^{9}	2.82×10^{9}
1c	255	---	---	---	---	1.23×10^{12}
2c	500	3.35×10^{12}	5.25×10^{12}	2.70×10^{12}	1.44×10^{12}	3.57×10^{11}
3c	1070	4.28×10^{10}	1.51×10^{11}*	---	4.33×10^{10}	1.09×10^{10}
4c	1370	7.90×10^{9}	3.21×10^{10}*	---	8.50×10^{9}	1.90×10^{9}

* 1 cm corrected to 2 cm by factor 1/1.46

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TABLE 4.4 - Results of Neutron Threshold Detector Measurements in 7 Inches of Lead and in Air (Bee)

Station No.	Slant Dist. (Yds.)	Measured Flux (n/cm^2) Thermal	Pu	Np	U	S
15a (lead)	490	1.78×10^{13}	3.0×10^{13}	1.3×10^{13}	4.8×10^{12}	4.83×10^{11}
14a	570	1.04×10^{13}	1.4×10^{13}	---	2.1×10^{12}	3.26×10^{11}
13a	645	5.09×10^{12}	9.8×10^{12}	4.4×10^{12}	1.4×10^{12}	1.74×10^{11}
12a	730	3.01×10^{12}	4.8×10^{12}	---	8.0×10^{11}	9.97×10^{10}
11a	805	1.98×10^{12}	2.8×10^{12}	1.4×10^{12}	4.7×10^{11}	6.54×10^{10}
10a	925	5.36×10^{11}	1.2×10^{12}	---	2.0×10^{11}	3.05×10^{10}
9a	1040	4.89×10^{11}	5.8×10^{11}	3.0×10^{11}	1.1×10^{11}	1.65×10^{10}
8a	1160	2.05×10^{11}	2.6×10^{11}	---	9.0×10^{10}	1.08×10^{10}
7a	1220	1.46×10^{11}	1.9×10^{11}	1.0×10^{11}	2.9×10^{10}	1.03×10^{10}
6a	1270	1.21×10^{11}	1.3×10^{11}	---	2.4×10^{10}	8.2×10^{9}
5a	1330	6.40×10^{10}	8.7×10^{10}	---	1.5×10^{10}	7.0×10^{9}
4a	1380	4.69×10^{10}	6.3×10^{10}	2.5×10^{10}	1.2×10^{10}	7.0×10^{9}
3a	1430	2.36×10^{10}	4.4×10^{10}	---	6.0×10^{9}	5.4×10^{9}
2a	1490	2.23×10^{10}	3.2×10^{10}	---	5.0×10^{9}	5.2×10^{9}
1a	1550	1.49×10^{10}	2.4×10^{10}	1.0×10^{10}	4.0×10^{9}	5.1×10^{9}
10c (air)	490	1.58×10^{13}	6.9×10^{13}*	---	1.5×10^{13}	3.25×10^{12}
9c	605	6.50×10^{12}	2.2×10^{13}	1.1×10^{13}	6.0×10^{12}	1.42×10^{12}
8c	720	2.57×10^{12}	8.7×10^{12}	4.7×10^{12}	2.6×10^{12}	6.25×10^{11}
7c	835	1.08×10^{12}	3.6×10^{12}*	---	1.2×10^{12}**	2.97×10^{11}
6c	955	6.60×10^{11}	1.8×10^{12}	8.0×10^{11}	5.2×10^{11}	1.34×10^{11}
5c	1070	2.58×10^{11}	9.6×10^{11}*	---	2.3×10^{11}**	5.99×10^{10}
4c	1190	1.12×10^{11}	3.8×10^{11}	2.0×10^{11}	1.0×10^{11}	3.05×10^{10}
3c	1310	6.65×10^{10}	1.65×10^{11}*	---	4.5×10^{10}**	1.52×10^{10}
2c	1430	2.68×10^{10}	9.6×10^{10}*	---	2.3×10^{10}**	9.90×10^{9}
1c	1550	1.30×10^{10}	4.0×10^{10}	2.0×10^{10}	1.1×10^{10}	7.00×10^{9}

* 1 cm ball extrapolated to 2 cm by factor 1/1.46

** 1 cm ball extrapolated to 2 cm by factor 1/1.10

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TABLE 4.5 - Results of Neutron Threshold Detector Measurements in 7 Inches of Lead and in Air (Wasp-Prime)

Station No.	Slant Dist. (Yds.)	Measured Flux (n/cm^2)				
		Thermal	Pu	Np	U	S
1a (lead)	280	4.90×10^{13}	5.7×10^{13}	2.4×10^{13}	8.0×10^{12}	Results not available
2a	375	2.30×10^{13}	2.2×10^{13}	---	3.1×10^{12}	
3a	430	1.26×10^{13}	1.5×10^{13}	7.0×10^{12}	2.1×10^{12}	
4a	485	8.06×10^{12}	---	---	---	
5a	550	3.69×10^{12}	5.7×10^{12}	2.8×10^{12}	8.0×10^{11}	
6a	650	2.48×10^{12}	2.8×10^{12}	---	4.4×10^{11}	
7a	760	8.56×10^{11}	1.4×10^{12}	7.0×10^{11}	2.1×10^{11}	
8a	865	7.06×10^{11}	---	---	---	
9a	910	5.74×10^{11}	5.7×10^{11}	2.4×10^{11}	8.3×10^{10}	
10a	960	3.47×10^{11}	---	---	---	
11a	995	2.72×10^{11}	3.4×10^{11}	---	5.2×10^{10}	
12a	1060	1.43×10^{11}	2.5×10^{11}	1.0×10^{11}	3.4×10^{10}	
13a	1110	1.18×10^{11}	1.85×10^{11}	---	2.8×10^{10}	
14a	1155	9.13×10^{10}	1.3×10^{11}	---	1.9×10^{10}	
15a	1205	7.17×10^{10}	1.1×10^{11}	6.0×10^{10}	1.7×10^{10}	
1c (air)	280	Results not available	1.0×10^{14}	5.4×10^{13}	2.7×10^{13}	Results not available
2c	350		6.9×10^{13}*	---	---	
3c	445		2.1×10^{13}*	---	5.7×10^{12}**	
4c	535		1.1×10^{13}	6.9×10^{12}	3.0×10^{12}	
5c	640		1.0×10^{13}*	---	1.6×10^{12}**	
6c	740		3.4×10^{12}*	---	---	
7c	845		---	---	---	
8c	965		6.9×10^{11}*	---	1.7×10^{11}*	
9c	1075		3.3×10^{11}	1.7×10^{11}	8.5×10^{10}	
10c	1185		1.7×10^{11}	8.5×10^{10}	4.3×10^{10}	

* 1 cm ball extrapolated to 2 cm by factor 1/1.46

** 1 cm ball extrapolated to 2 cm by factor 1/1.10

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TABLE 4.6 - Threshold Detector Measurement of Neutron Dose in Rep inside and outside 7-inch Lead Exposure Containers Versus Slant Distance (Wasp, Moth, Hornet, Bee, and Wasp-Prime)

WASP			MOTH			HORNET			BEE			WASP-PRIME		
Station No.	Distance (yds.)	Dose (rep)	Station No.	Distance (yds.)	Dose (rep)	Station No.	Distance (yds.)	Dose (rep)	Station No.	Distance (yds.)	Dose (rep)	Station No.	Distance (yds.)	Dose (rep)
Inside														
1a	310	20900	1a	255	32800	15a	255	55500	15a	490	53200	1a	280	99200
2a	390	9600	2a	305	18600	14a	305	28000	14a	570	23400	2a	375	36600
3a	440	5760	3a	375	8980	13a	375	15500	13a	645	17500	3a	430	27100
4a	495	3920	4a	450	4580	12a	450	10860	12a	730	8300	4a	485	---
5a	640	2920	5a	530	2310	11a	530	5925	11a	805	5275	5a	550	10500
6a	760	570	6a	640	985	10a	640	2640	10a	925	2100	6a	650	4750
7a	875	275	7a	755	420	9a	755	1175	9a	1040	1140	7a	760	2600
8a	985	140	8a	875	195	8a	875	505	8a	1160	530	8a	865	---
9a	1015	110	9a	925	140	7a	925	360	7a	1220	370	9a	910	1000
10a	1070	85	10a	975	100	6a	975	255	6a	1270	250	10a	960	---
11a	1100	70	11a	1020	75	5a	1020	190	5a	1330	175	11a	995	575
12a	1150	50	12a	1070	55	4a	1070	140	4a	1380	115	12a	1060	425
13a	1190	40	13a	1120	40	3a	1120	100	3a	1430	90	13a	1110	310
14a	1225	35	14a	1180	25	2a	1180	70	2a	1490	65	14a	1155	220
15a	1270	25	15a	1245	20	1a	1245	45	1a	1550	40	15a	1205	210
Outside														
1c	310	41000	1c	255	78400	1x*	270	185000	10c	490	126000	1c	280	204500
2c	370	22600	2c	365	21600	2x	365	63200	9c	605	43700	2c	350	---
3c	515	6600	3c	480	8050	3x	480	17100	8c	720	18000	3c	445	40600
4c	650	2400	4c	600	3120	4x	600	6750	7c	835	7400	4c	535	24000
5c	755	1300	5c	715	1325	5x	715	3275	6c	955	3460	5c	640	17150
6c	855	680	6c	835	565	6x	835	1300	5c	1070	1800	6c	740	---
7c	955	340	7c	955	285	7x	955	600	4c	1190	770	7c	845	---
8c	1060	185	8c	1070	130	8x	1090	295	3c	1310	300	8c	965	1300
9c	1155	105	9c	1190	60	9x	1210	130	2c	1430	170	9c	1075	660
10c	1250	60	10c	1310	30	10x	1330	65	1c	1550	85	10c	1185	335
						1c	255	---						
						2c	500	10560						
						3c	1070	395						
						4c	1370	80						

* "x" stations are relocated "c" stations for this specific shot.

[redacted]

TABLE 4.7 - Results of Chloroform-Phase Dosimeter Measurements of Neutron and Gamma Radiation Dose inside Lead and Aluminum Exposure Containers (Wasp)

Station No.	Slant Dist. (yds.)	1/2-Phase γ (rep)	1-Phase Neutron (rep)*	2-Phase γ (rep)
1a (lead)	310	1700	17000	
2a	390	700	7400	
3a	440	450	4700	
4a	495	235	2600	
5a	640	80-100	900	
6a	760	35	350	
7a	875	Too Low	150 $\pm$ 50	
8a	985	to	Too Low	
9a	1015	Measure	to	
10a	1070		Measure	
11a	1100			
12a	1150			
13a	1190			
14a	1225			
15a	1270			
1b (aluminum)	310	15500	31000	18200
2b	400	7000	14000	7000
3b	475	3600	6600	3700
4b	530	2500	4100	2200
5b	645	1200	1750	1200
6b	810	600	600	550
7b	950	210	300	200
8b	1065	100	150 $\pm$ 50	110
9b	1115	80	Too Low to	90-100
10b	1160	60	Measure	50
11b	1205	70		75
12b	1260	70		100
13b	1305	70		80
14b	1360	60		50
15b	1405	40		50

* Results are given "as read" and may be increased by 30 per cent in keeping with preliminary calibrations of the chemical dosimeters against the fission foil system.

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TABLE 4.8 - Results of Chloroform-Phase Dosimeter Measurements of Neutron and Gamma Radiation Dose inside Lead and Aluminum Exposure Containers (Moth)

Station No.	Slant Dist. (yds.)	1/2-Phase γ (rep)	1-Phase Neutron (rep)*	2-Phase γ (rep)
1a (lead)	255	2400	23000	
2a	305	1300	12100	
3a	375	610	6700	
4a	450	300	2750	
5a	530	155	1500	
6a	640	70	600	
7a	755	30	270	
8a	875	Too Low to	150 $\pm$ 50	
9a	925	Measure	Too Low to	
10a	975		Measure	
11a	1020			
12a	1070			
13a	1120			
14a	1180			
15a	1245			
1b (aluminum)	280	20400	55000	60000
2b	345	10500	22000	34000
3b	420	5000	10000	11500
4b	500	3100	4800	6000
5b	560	2240	2800	4000
6b	685	940	1400	1500
7b	805	430	550	420
8b	945	220	300	250
9b	995	160	150 $\pm$ 50	150
10b	1050	120	Too Low to	100
11b	1110	100	Measure	100
12b	1180	70		100
13b	1240	55		70
14b	1300	55		50
15b	1370	55		50

* Results are given "as read" and may be increased by 30 per cent in keeping with preliminary calibrations of the chemical dosimeters against the fission foil system.

[redacted]

TABLE 4.9 - Results of Chloroform-Phase Dosimeter Measurements of Neutron and Gamma Radiation Dose inside Lead and Aluminum Exposure Containers (Hornet)

Station No.	Slant Dist. (yds.)	1/2-Phase γ (rep)	1-Phase Neutron (rep)*	2-Phase γ (rep)
15a (lead)	255	6800	46000	
14a	305	3000	23000	
13a	375	1620	13000	
12a	450	1000	8500	
11a	530	500	4600	
10a	640	210	2300	
9a	755	90	950	
8a	875	Too Low	400	
7a	925	to	250	
6a	975	Measure	Too Low to	
5a	1020		Measure	
4a	1070			
3a	1120			
2a	1180			
1a	1245			
15b (aluminum)	280	38000	155000	68000
14b	345	19250	48000	56700
13b	420	12000	22000	25000
12b	500	6000	11000	11000
11b	560	4400	6700	8000
10b	685	2000	2800	3300
9b	805	1100	1300	1100
8b	945	680	450	580
7b	995	400	350	385
6b	1050	375	200	300
5b	1110	200	Too Low to	200
4b	1180	200	Measure	140
3b	1240	150		135
2b	1300	100		90
1b	1370	100		90

* Results are given "as read" and may be increased by 30 per cent in keeping with preliminary calibrations of the chemical dosimeters against the fission foil system.

[redacted]

TABLE 4.10 - Results of Chloroform-Phase Dosimeter Measurements of Neutron and Gamma Radiation Dose inside Lead and Aluminum Exposure Containers (Bee)

Station No.	Slant Dist. (yds.)	1/2-Phase γ (rep)	1-Phase Neutron (rep)*	2-Phase γ (rep)
15a (lead)	490	5300	45000	
14a	570	2700	22000	
13a	645	1700	12000	
12a	730	680	6700	
11a	805	380	3500	
10a	925	160	1500	
9a	1040	70	750	
8a	1160	Too Low to	350	
7a	1220	Measure	260	
6a	1270		Too Low to	
5a	1330		Measure	
4a	1380			
3a	1430			
2a	1490			
1a	1550			
15b (aluminum)	550	21000	66000	24500
14b	625	13000	35000	15000
13b	710	7000	17500	7200
12b	795	4400	9000	4600
11b	895	2300	4500	2450
10b	1015	1200	2200	1155
9b	1150	700	900	770
8b	1310	530	400	480
7b	1360	300	280	310
6b	1430	210	Too Low to	200
5b	1510	150	Measure	130
4b	1590	100		100
3b	1660	80		100
2b	1730	70		75
1b	1810	50		50

* Results are given "as read" and may be increased by 30 per cent in keeping with preliminary calibrations of the chemical dosimeters against the fission foil system.

[redacted]

TABLE 4.11 - Results of Chloroform-Phase Dosimeter Measurements of Neutron and Gamma Radiation Dose inside Lead and Aluminum Exposure Containers (Wasp-Prime)

Station No.	Slant Dist. (yds.)	1/2-Phase γ (rep)	1-Phase Neutron (rep)*	2-Phase γ (rep)
1a (lead)	280	7000	66000	
2a	375	3000	26000	
3a	430	1650	15000	
4a	485	950	8800	
5a	550	680	6000	
6a	650	280	2500	
7a	760	130	1100	
8a	865	60	580	
9a	910	40	350	
10a	960	Too Low to Measure	200	
11a	995		Too Low to Measure	
12a	1060			
13a	1110			
14a	1155			
15a	1205			
1b (aluminum)	280	72000	143000	---
2b	380	28400	44000	44000
3b	460	14000	22000	23000
4b	520	10000	13500	---
5b	600	5200	7000	7500
6b	710	3600	3500	3950
7b	835	1500	1400	2600
8b	945	890	650	900
9b	995	650	450	700
10b	1045	600	300	600
11b	1100	400	250	---
12b	1160	300	Too Low to Measure	300
13b	1225	220		200
14b	1280	175		190
15b	1335	140		150

* Results are given "as read" and may be increased by 30 per cent in keeping with preliminary calibrations of the chemical dosimeters against the fission foil system.

[redacted]

TABLE 4.12 - Results of Film Badge Measurements (Wasp)

Station No.	Slant Distance (yds.)	Film Badge Reading (r)	Station No.	Slant Distance (yds.)	Film Badge Reading (r)
(Inside Lead Hemispheres)			(Inside Aluminum Hemispheres)		
1a	310	10,900	1b	310	30,000
2a	390	1,600	2b	400	16,500
3a	440	830	3b	475	5,350
4a	495	560	4b	530	2,750
5a	640	230	5b	645	980
6a	760	140	6b	810	470
7a	875	65	7b	950	240
8a	985	35	8b	1065	130
9a	1015	25	9b	1115	100
10a	1070	20	10b	1160	90
11a	1100	16	11b	1205	65
12a	1150	13	12b	1260	50
13a	1190	12	13b	1305	40
14a	1225	7.5	14b	1360	30
15a	1270	7.5	15b	1405	25
(Outside Stations)			(Li Wrapped Dosimeters)		
1c	310	29,000	1b	310	25,000
		30,000			
2c	370	15,000	4b	530	2,600
		15,000			
3c	515	3,000	6b	810	420
		3,200			
4c	650	1,150	11b	1205	55
		1,100			
5c	755	570	15b	1405	30
		570			
6c	855	400			
		400			
7c	955	250			
		250			
8c	1060	140			
		140			
9c	1155	100			
		90			
10c	1250	60			
		60			

[redacted]

TABLE 4.13 - Results of Film Badge Measurements (Moth)

Station No.	Slant Distance (yds.)	Film Badge Reading (r)	Station No.	Slant Distance (yds.)	Film Badge Reading (r)
(Inside Lead Hemispheres)			(Inside Aluminum Hemispheres)		
1a	255	---	1b	280	65,000
2a	305	5,300	2b	345	27,000
3a	375	1,390	3b	420	14,500
4a	450	770	4b	500	3,600
5a	530	380	5b	560	1,900
6a	640	190	6b	685	770
7a	755	90	7b	805	470
8a	875	45	8b	945	220
9a	925	30	9b	995	180
10a	975	20	10b	1050	170
11a	1020	12	11b	1110	130
12a	1070	8	12b	1180	70
13a	1120	6	13b	1240	55
14a	1180	4	14b	1300	45
15a	1245	3.5	15b	1370	17
(Outside Stations)			(Li Wrapped Dosimeters)		
1c	255	44,000	1b	280	52,000
		42,000			
2c	365	15,000	4b	500	2,600
		16,000			
3c	480	4,600	6b	685	750
		4,750			
4c	600	1,350	11b	1110	70
		1,400			
5c	715	700	15b	1370	30
		670			
6c	835	390			
		390			
7c	955	230			
		230			
8c	1070	130			
		130			
9c	1190	55			
		55			
10c	1310	40			
		40			

[redacted]

TABLE 4.14 - Results of Film Badge Measurements (Hornet)

Station No.	Slant Distance (yds.)	Film Badge Reading (r)	Station No.	Slant Distance (yds.)	Film Badge Reading (r)
(Inside Lead Hemispheres)			(Inside Aluminum Hemispheres)		
1a	1245	5.5	1b	1370	65
2a	1180	6	2b	1300	75
3a	1120	12	3b	1240	110
4a	1070	20	4b	1180	120
5a	1020	30	5b	1110	210
6a	975	45	6b	1050	230
7a	925	70	7b	995	260
8a	875	90	8b	945	420
9a	755	170	9b	805	800
10a	640	300	10b	685	1,200
11a	530	800	11b	560	11,000
12a	450	1,450	12b	500	13,000
13a	375	370	13b	420	28,000
14a	305	12,000	14b	345	13,000
15a	255	36,000	15b	280	Too High to Read

(Outside Stations)		
1x	270	---
2x	365	---
3x	480	--- 14,000
4x	600	3,100 3,150
5x	715	1,200 1,200
6x	835	1,150 1,150
7x	955	600 600
8x	1090	370 370
9x	1210	210 220
10x	1330	120 120

[redacted]

TABLE 4.15 - Results of Film Badge Measurements (Bee)

Station No.	Slant Distance (yds.)	Film Badge Reading (r)	Station No.	Slant Distance (yds.)	Film Badge Reading (r)
(Inside Lead Hemispheres)			(Inside Aluminum Hemispheres)		
1a	1550	3	1b	1810	20
2a	1490	3.6	2b	1730	30
3a	1430	4.5	3b	1660	40
4a	1380	14	4b	1590	50
5a	1330	18	5b	1510	60
6a	1270	35	6b	1430	100
7a	1220	45	7b	1360	140
8a	1160	65	8b	1310	180
9a	1040	120	9b	1150	330
10a	925	220	10b	1015	360
11a	805	490	11b	895	1130
12a	730	720	12b	795	1650
13a	645	1080	13b	710	3800
14a	570	1800	14b	625	10,500
15a	490	3600	15b	550	20,000
(Outside Stations)					
1c	1550	65			
		55			
2c	1430	85			
		90			
3c	1310	170			
		170			
4c	1190	270			
		270			
5c	1070	470			
		440			
6c	955	850			
		870			
7c	835	1550			
		1700			
8c	720	3250			
		3050			
9c	605	---			

10c	490	---			

[redacted]

TABLE 4.16 - Results of Film Badge Measurements (Wasp-Prime)

Station No.	Slant Distance (yds.)	Film Badge Reading (r)	Station No.	Slant Distance (yds.)	Film Badge Reading (r)
(Inside Lead Hemispheres)			(Inside Aluminum Hemispheres)		
1a	280	18,000	1b	280	---
2a	375	2,450	2b	380	38,000
3a	430	1,650	3b	460	5,100
4a	485	900	4b	520	3,300
5a	550	650	5b	600	1,850
6a	650	360	6b	710	1,330
7a	760	200	7b	835	730
8a	865	120	8b	945	520
9a	910	95	9b	995	400
10a	960	55	10b	1045	340
11a	995	40	11b	1100	230
12a	1060	30	12b	1160	240
13a	1110	25	13b	1225	200
14a	1155	20	14b	1280	75
15a	1205	20	15b	1335	120
(Outside Stations)			(Li Wrapped Dosimeters)		
1c	280	---	1a	280	8,300
		---	2a	375	2,900
2c	350	---	3a	430	1,750
		---	4a	485	890
3c	445	---	5a	550	650
		---	6a	650	390
4c	535	9,000	7a	760	230
		3,150	8a	865	120
5c	640	2,850	9a	910	110
		1,750	10a	960	70
6c	740	1,500	11a	995	45
		1,000	12a	1060	30
7c	845	990	13a	1110	35
		610			
8c	965	590			
		390			
9c	1075	370			
		290			
10c	1185	250			
		200			

[redacted]

TABLE 4.17 - Tissue-Equivalent and Graphite Ion Chamber Measurements (Wasp)

Chamber Type	Charging Voltage	Chamber Reading* (rep)							
		Sta. 1d (780 yds.)	Sta. 2d (850 yds.)	Sta. 3d (970 yds.)	Sta. 4d (1100 yds.)	Sta. 5d (1180 yds.)	Sta. 6d (1245 yds.)	Sta. 7d (1325 yds.)	Sta. 8d (1400 yds.)
High Dose Tissue-Equivalent	-730	528	372	237		Out			
	+730	465	268	131		28			
	-600	500	Out	220					
	+600	425	254	137		106			
	-400	572	329	180	134	89			
	+400	456	308	Out	Out				
	-200	458	288	141	69				
	+200	451	246	135	Out				
Low Dose Tissue-Equivalent	-730				37		26	Out	4
	+730				36		17	15	14
	-600				41		20	14	14
	+600				33		21	10	13
	-400					23	22	16	10
	+400					25	17	15	13
	-200					15	11	7	6
	+200					18	13	10	7
High Dose Graphite CO_2	-730	266	250	148		100			
	+730	206	162	64		107			
	-600	254	258	110		Out			
	+600	233	189	120		85			
	-400	240	190	89	64				
	+400	311	249	97	40				
	-200	220	148	83	46				
	+200	Out	106	78	Out				
Low Dose Graphite CO_2	-730				29		14	11	5
	+730				33		10	6	4
	-600				29		25	9	
	+600				29		12	14	2
	-400					Out	14	14	11
	+400					12	14	10	12
	-200					13	10	7	4
	+200					13	9	7	5

* Tentative values only, as final numerical data will have to await detailed computations based on final calibration studies.

[redacted]

TABLE 4.18 - Tissue-Equivalent and Graphite Ion Chamber Measurements (Moth)

Chamber Type	Charging Voltage	Chamber Reading* (rep)							
		Sta. 1d (670 yds.)	Sta. 2d (765 yds.)	Sta. 3d (860 yds.)	Sta. 4d (1000 yds.)	Sta. 5d (1100 yds.)	Sta. 6d (1200 yds.)	Sta. 7d (1300 yds.)	Sta. 8d (1400 yds.)
High Dose Tissue-Equivalent	-730	675	471	365					
	+730	761	426	183					
	-600	804	540	225					
	+600	673	372	196					
	-400	800	332	167					
	+400	920	502	279					
	-200	598	376	185					
	+200	Out	332	195					
Low Dose Tissue-Equivalent	-730				29.6		21.6	Out	6.5
	+730				43.8		23.1	6.9	4.6
	-600				Out		15.1	8.6	4.3
	+600				46.2		18.5	13.9	Out
	-400					25.9	15.1	13.0	4.3
	+400					25.4	18.5	16.2	6.9
	-200					16.4	10.6	Out	4.5
	+200					16.2	11.8	5.1	4.2
High Dose Graphite CO_2	-730	339	352	148					
	+730	254	135	129					
	-600	403	219	Out					
	+600	Out	189	87					
	-400	251	131	119					
	+400	394	452	167					
	-200	226	140	92					
	+200	306	125	78					
Low Dose Graphite CO_2	-730				21.8	33.3	9.1	1.8	5.4
	+730				34.9	Out	11.7	7.8	7.8
	-600				29.0	Out	18.1	3.6	Out
	+600				31.0	Out	13.6	11.7	3.9
	-400				31.8	12.7	5.4	1.8	0.0
	+400				Out	15.6	9.7	2.0	3.9
	-200					12.3	7.6	5.4	2.4
	+200					10.9	6.2	3.1	2.3

* Tentative values only, as final numerical data will have to await detailed computations based on final calibration studies.

[redacted]

TABLE 4.19 - Tissue-Equivalent and Graphite Ion Chamber Measurements (Hornet)

Chamber Type	Charging Voltage	Chamber Reading* (rep) Sta. 2d (1300 yds.)	Sta. 3d (1200 yds.)	Sta. 4d (1100 yds.)	Sta. 5d (1000 yds.)	Sta. 6d (865 yds.)	Sta. 7d (765 yds.)	Sta. 8d (670 yds.)
High Dose Tissue-Equivalent	-730			Out		96	220	680
	+730			Out		408	370	3100
	-600			Out		260	250	460
	+600			Out		600	415	820
	-400				Out	184	Out	580
	+400				480	210	308	760
	-200				Out	290	Out	690
	+200				100	215	Out	770
Low Dose Tissue-Equivalent	-730	5.4	21		Out			
	+730	13.8	40		71			
	-600	18.5	20.8		55.2			
	+600	12.2	26.5		Out			
	-400	18.5	16.4	26.6				
	+400	12.5	21.5	32.2				
	-200	13.0	32.0	24.6				
	+200	8.2	Out	24				
High Dose Graphite CO_2	-730			350		355	1000	Out
	+730			Out		Out	215	Out
	-600			93		Out	113	Out
	+600			540		74	Out	Lost
	-400				Out	Out	135	292
	+400				Out	45	Out	317
	-200				Out	66	Out	Out
	+200				63	111	Out	298
Low Dose Graphite CO_2	-730	2.5	138		38			
	+730	38	Out		42.3			
	-600	Out	9.0		Out			
	+600	Out	9.8		41			
	-400	9.0	5.0	22				
	+400	10.6	15.8	17.8				
	-200	13.4	24	5.3				
	+200	7.2	12.8	19.2				

* Tentative values only, as final numerical data will have to await detailed computations based on final calibration studies.

[redacted]

TABLE 4.20 - Tissue-Equivalent and Graphite Ion Chamber Measurements (Bee)

Charging Voltage	Chamber Type and Chamber Rdg.* (rep)			
	High Dose Tissue-Equivalent		Low Dose Tissue-Equivalent	
	Sta. 5d (1275 yds.)	Sta. 6d (1075 yds.)	Sta. 7d (960 yds.)	Sta. 8d (845 yds.)
-730	86	?	697	1450
-730		230		1420
-730				1560
+730	95	213	742	1605
+730		224		1605
-600	79	281	790	1660
-600		187		Out
+600	72	194	1020	1680
+600		187		1800
+600				1500
-400	59	149	762	2250
-400	100			
+400	54	147	706	1710
+400	58		Out	
+400			Out	
-200	78	97.2	720	Discharged
-200	42		Out	
+200	44	104	1000	940
+200	51		728	
	High Dose Graphite CO_2		Low Dose Graphite CO_2	
-730	67	154	324	602
-730	72	316		920
-730	63	150		
+730		453	344	890
+730		174		736
+730		158		
-600	58	229	427	900
-600	Out	380		1125
-600	58.5	353		1190
+600	61	178	2540	670
+600	82	263		Out
+600		163		820
-400	95	259	424	780
-400	58			
-400	54			
+400	51	123	393	880
+400	76	118	291	Discharged
+400	42.5		277	
-200	68	83.7	462	892
-200	41	153	580	
-200	46			
+200	42	75	355	600
+200	64	91	312	800
+200	41		347	

* Tentative values only, as final numerical data will have to await detailed computations based on final calibration studies.

[redacted]

TABLE 4.21 - Tissue-Equivalent and Graphite Ion Chamber Measurements (Wasp-Prime)

Charging Voltage	Chamber Type and Chamber Rdg.* (rep)			
	High Dose Tissue-Equivalent		Low Dose Tissue-Equivalent	
	Sta. 1d (575 yds.)	Sta. 2d (780 yds.)	Sta. 3d (860 yds.)	Sta. 4d (980 yds.)
-730	Discharged	856	?	139
-730	2770	908	320	
-730				94
+730	2870	1200	251	167
+730	2790		263	
-600	Discharged	918	236	136
+600	2840	990	243	123
+600	2210		234	
-400	Discharged		192	99
-400				171
+400	Discharged	782	195	112
+400				118
-200	Discharged	Discharged	Discharged	119
-200				73
+200		1040	Discharged	78
+200				80
+200				
	High Dose Graphite CO_2		Low Dose Graphite CO_2	
-730	1720	446	183	120
-730	1920		192	96
-730			486	
+730	2420	395	220	105
+730			195	
-600	2000		390	?
-600	1480		335	98
-600			177	
+600	1330	640	208	123
+600			172	147
+600				186
-400		388	304	105
-400			158	80
+400	1180	452	166	91
+400	1435	384	376	91
+400	Discharged			101
-200	Discharged	433	Discharged	63
-200		476	Discharged	88
-200			100	116
+200	950	536	94	71
+200	1360		104	
+200	1180		204	

* Tentative values only, as final numerical data will have to await detailed computations based on final calibration studies.

[redacted]

TABLE 4.22 - Results of Biological Measurements inside Lead and Aluminum Stations (Wasp)

Station No.	Slant Distance (yds.)	Body Weight Loss: Loss (per cent)	Body Weight Loss: Dose (rem)	Spleen-Thymus Wt. Loss: Spleen (per cent)	Spleen-Thymus Wt. Loss: Thymus (per cent)	Dose: Spleen (rem)	Dose: Thymus (rem)	Median Survival: Time (hrs.)	Median Survival: Dose (rem)
(Neutrons)									
1a	310							39	25000
2a	390							55	15000
3a	440							Frozen	
4a	495							85	1200 to 10000
5a	640							Frozen	
6a	760	14.7						110	1050
7a	875	11.3		34.9	18.6	575	635		
8a	985	2.8		48.8	36.9	355	375		
9a	1015	2.3		63.5	43.8	185	310		
10a	1070	1.4		61.8	54.1	205	230		
11a	1100			Lost Due to Freezing					
12a	1150								
13a	1190								
14a	1225								
15a	1270								
(Neutrons + Gamma)									
1b	310							27	35000
2b	400							52	17000
3b	475							84	1200 to 10000
4b	530							69	" "
5b	645	32.6						85	" "
6b	810	29.9						86	" "
7b	950	17.6		32.8	19.0	615	635		
8b	1065	12.1		43.2	42.4	420	325		
9b	1115	6.0		51.1	47.0	325	280		
10b	1160	5.7		54.9	67.6	280	140		
11b	1205	4.5		69.7	61.8	125	155		
12b	1260	3.7		65.4	71.6	165	120		
13b	1305	1.4		75.8	78.8	65	80		
14b	1360	1.3		75.8	83.5	65	60		
15b	1405	1.1		86.8	89.8	~25	30		

[redacted]

TABLE 4.23 - Results of Biological Measurements inside Lead and Aluminum Stations (Moth)

Station No.	Slant Distance (yds.)	Body Weight Loss: Loss (per cent)	Body Weight Loss: Dose (rem)	Spleen-Thymus Wt. Loss: Spleen (per cent)	Spleen-Thymus Wt. Loss: Thymus (per cent)	Dose: Spleen (rem)	Dose: Thymus (rem)	Median Survival: Time (hrs.)	Median Survival: Dose (rem)
(Neutrons)									
1a	255							53	16000
2a	305							60	13000
3a	375							98	1200 to 10000
4a	450	34.4						84	" "
5a	530	32.7						82	" "
6a	640	28.8						90	" "
7a	755	19.5						?	
8a	875	10.6		48.0	40.5	376	329		
9a	925	7.3		59.2	50.6	229	253		
10a	975	0.7		64.3	65.9	170	143		
11a	1020	2.7		71.3	70.1	105	124		
12a	1070	3.2		80.8	75.1	26	97		
13a	1120	2.4		75.5	84.5	72	50		
14a	1180	--		85.6	96.8	--	--		
15a	1245	--		94.1	88.6	--	30		
(Neutrons + Gamma)									
1b	280								Dead Blast
2b	345							35	27000
3b	420							46	20000
4b	500							58	13000
5b	560							86	1200 to 10000
6b	685							86	" "
7b	805	29.7						84	" "
8b	945	17.1		34.3	21.2	682	589		
9b	995	13.8		39.5	29.4	490	464		
10b	1050	6.1		40.8	37.9	477	388		
11b	1100	7.2		55.9	59.8	268	187		
12b	1180	4.6		70.2	72.8	111	109		
13b	1240	1.2		70.7	75.2	110	97		
14b	1300	--		75.5	83.1	72	58		
15b	1370	--		82.0	>100.0	14	--		

[redacted]

TABLE 4.24 - Results of Biological Measurements inside Lead and Aluminum Stations (Hornet)

Station No.	Slant Distance (yds.)	Body Weight Loss: Loss (per cent)	Body Weight Loss: Dose (rem)	Spleen-Thymus Wt. Loss: Spleen (per cent)	Spleen-Thymus Wt. Loss: Thymus (per cent)	Dose: Spleen (rem)	Dose: Thymus (rem)	Median Survival: Time (hrs.)	Median Survival: Dose (rem)
(Neutrons)									
1a	1245	--		84.0	89.6	26	30		
2a	1180	0.6		80.3	96.0	33	19		
3a	1120	5.0		75.8	87.2	65	38		
4a	1070	5.0		59.6	70.3	220	125		
5a	1020	9.9		41.3	41.1	465	335		
6a	975	9.4		35.5	34.9	560	400		
7a	925	13.1		28.9	19.9	700	615		
8a	875	17.9		19.6	8.5	955	950		
9a	755	26.8						75	1200 to 10000
10a	640	28.0						78	" "
11a	530	30.8						80	" "
12a	450							60	12000
13a	375							45.5	20000
14a	305							40	24000
15a	255							14	52000
(Neutrons + Gamma)									
1b	1370	4.6		84.4	85.0	--	50		
2b	1300	5.0		61.1	69.7	210	135		
3b	1240	8.0		56.4	51.3	260	245		
4b	1180	8.0		52.6	48.7	305	270		
5b	1110	14.6		37.7	30.3	525	455		
6b	1050	19.8		24.9	10.0	795	885		
7b	995	21.7						140	970
8b	945	24.7						83	1200 to 10000
9b	805	36.4						79	" "
10b	685	31.8						85	" "
11b	560							62	12000
12b	500							48	19000
13b	420							48	19000
14b	345							Dead Blast	
15b	280							Dead Blast	

[redacted]

TABLE 4.25 - Results of Biological Measurements inside Lead and Aluminum Stations (Bee)

Station No.	Slant Distance (yds.)	Body Weight Loss: Loss (per cent)	Body Weight Loss: Dose (rem)	Spleen-Thymus Wt. Loss: Spleen (per cent)	Spleen-Thymus Wt. Loss: Thymus (per cent)	Dose: Spleen (rem)	Dose: Thymus (rem)	Median Survival: Time (hrs.)	Median Survival: Dose (rem)
(Neutrons)									
1a	1550	0.4		87.9	100.8	-	-		
2a	1490	1.0		97.7	96.7	-	-		
3a	1430	2.5		71.4	84.3	107	55		
4a	1380	0.7		73.7	71.5	85	125		
5a	1330	4.2		55.4	53.4	275	235		
6a	1270	8.3		47.7	42.9	375	315		
7a	1220	10.5		40.9	33.0	470	420		
8a	1160	16.5		30.1	18.4	675	650		
9a	1040	23.3						84	1200 to 10000
10a	925	26.2						82	" "
11a	805	30.8						86	" "
12a	730	33.6						87	" "
13a	645							49	18000
14a	570							46	20000
15a	490							37	26000
(Neutrons + Gamma)									
1b	1810	0.6		87.4	100.6	-	-		
2b	1730	2.0		80.9	85.2	26	50		
3b	1660	1.1		79.0	69.8	39	130		
4b	1590	2.6		69.4	54.7	125	225		
5b	1510	3.8		56.3	46.0	260	290		
6b	1430	6.2		46.4	24.3	385	405		
7b	1360	9.5		39.0	19.9	505	615		
8b	1310	18.3		27.8	9.5	725	905		
9b	1150	31.9						82	1200 to 10000
10b	1015	29.7						80	" "
11b	895	31.0						87	" "
12b	795	36.0						78	" "
13b	710							50	17000
14b	625							42	23000
15b	550							16	48000

[redacted]

TABLE 4.26 - Results of Biological Measurements inside Lead and Aluminum Stations (Wasp-Prime)

Station No.	Slant Distance (yds.)	Body Weight Loss: Loss (per cent)	Body Weight Loss: Dose (rem)	Spleen-Thymus Wt. Loss: Spleen (per cent)	Spleen-Thymus Wt. Loss: Thymus (per cent)	Dose: Spleen (rem)	Dose: Thymus (rem)	Median Survival: Time (hrs.)	Median Survival: Dose (rem)
(Neutrons)									
1a	280							2	100000
2a	375							32	29000
3a	430							36	26000
4a	485							48	19000
5a	550	36.8						80	1200 to 10000
6a	650	29.6						~80	" "
7a	760	30.3						~80	" "
8a	865	29.2						~80	" "
9a	910	27.6						~80	" "
10a	960	24.8						105	1100
11a	995	23.3		21.3	10.5	895	865		
12a	1060	17.0		26.4	16.3	760	695		
13a	1110	11.6		31.9	23.3	635	555		
14a	1155	12.0		39.2	28.8	495	475		
15a	1205	8.2		48.4	45.6	360	295		
(Neutrons + Gamma)									
1b	280								Dead Blast
2b	380							2.5	100000
3b	460							37	26000
4b	520							35	28000
5b	600	36.6						63	12000
6b	710	32.2						~84	1200 to 10000
7b	835	33.3						~84	" "
8b	945	33.0						~84	" "
9b	995	30.3						~84	" "
10b	1045	26.9						~84	" "
11b	1100	24.0						120	1000
12b	1160	18.6		21.2	11.6	900	830		
13b	1225	15.5		28.2	16.3	710	695		
14b	1280	11.2		36.1	32.6	550	425		
15b	1335	6.9		41.2	41.6	465	330		

[redacted]

TABLE 5.1 Intercept-Constant Terms for Thermal Neutron Data (Wasp, Moth, Hornet, Bee, and Wasp-Prime)

	Flux (n/cm^2)	Neutrons ($n/cm^2/kt$)	Dose (rep)
Wasp	1.12×10^{16}	9.3×10^{15}	4.8×10^{5}
Moth	9.60×10^{15}	3.8×10^{15}	4.2×10^{5}
Hornet	2.00×10^{16}	5.5×10^{15}	8.8×10^{5}
Bee	1.23×10^{17}	1.5×10^{16}	5.3×10^{6}
Wasp-Prime	6.03×10^{16}	1.9×10^{16}	2.6×10^{6}

TABLE 5.2 - Factors for Conversion of Neutron Detector Data to Neutron Dose in Rep

	Energy Region	Dose ($rep/n/cm^2$)
Pu flux - Np flux	4 kev - 0.72 mev	1.0×10^{-9}
Np flux - U flux	0.72 mev - 1.5 mev	2.5×10^{-9}
U flux - S flux	1.5 mev - 2.5 mev	3.2×10^{-9}
S flux	>2.5 mev	3.9×10^{-9}

[redacted]

TABLE 5.3 - The Per Cent of the Total Neutrons in Each Interval and the Per Cent of Total Neutron Dose (in rep) Delivered (Wasp, Moth, Hornet, Bee and Wasp-Prime)

Energy Range	Wasp		Moth		Hornet		Bee		Wasp-Prime	
	In Air	In Lead	In Air	In Lead	In Air	In Lead	In Air	In Lead	In Air	In Lead
(Per cent of Total Neutrons)										
4 kev to 0.72 mev	49.0	49.0	52.5	58.5	51.5	51.5	48.0	56.0	49.0	49.0
0.72 mev to 1.5 mev	25.5	34.0	22.0	26.5	14.5	27.5	23.7	26.7	24.0	35.5
1.5 mev to 2.5 mev	20.1	15.5	20.3	13.7	25.0	18.4	20.3	15.0	22.6	14.1
> 2.5 mev	5.4	1.5	5.2	1.3	9.0	2.6	8.0	2.3	5.4	1.4
[Per cent of Total Neutron Dose (in rep)]										
4 kev to 0.72 mev	24.1	25.9	27.2	33.1	25.4	27.2	23.6	31.2	24.6	26.0
0.72 mev to 1.5 mev	32.2	44.8	28.6	38.3	17.9	36.3	29.2	37.1	30.1	47.1
1.5 mev to 2.5 mev	32.4	26.2	33.7	25.6	39.4	31.1	31.9	26.7	34.7	23.9
> 2.5 mev	10.7	3.1	10.5	3.0	17.3	5.4	15.3	5.0	10.6	3.0

[redacted]

TABLE 5.4 - Formulae for Neutron Dose (in rep) Inside and Outside Lead Stations, as a Function of Distance, Derived from Foil Data (Wasp, Moth, Hornet, Bee, and Wasp-Prime)

	Dose in rep		Ratio of Dose Inside/Outside
	In Air	In Lead	
Wasp	$\frac{1.34 \times 10^{10} e^{-D/250}}{D^2}$	$\frac{6.68 \times 10^{9} e^{-D/250}}{D^2}$	0.50
Moth	$\frac{1.38 \times 10^{10} e^{-D/235}}{D^2}$	$\frac{6.05 \times 10^{9} e^{-D/235}}{D^2}$	0.44
Hornet	$\frac{3.04 \times 10^{10} e^{-D/235}}{D^2}$	$\frac{1.51 \times 10^{10} e^{-D/235}}{D^2}$	0.50
Bee	$\frac{2.42 \times 10^{11} e^{-D/220}}{D^2}$	$\frac{1.26 \times 10^{11} e^{-D/220}}{D^2}$	0.52
Wasp-Prime	$\frac{4.36 \times 10^{10} e^{-D/270}}{D^2}$	$\frac{2.42 \times 10^{10} e^{-D/270}}{D^2}$	0.56

D = distance in yds.

[redacted]

TABLE 5.5 Formulae for Neutron Dose (in rep) inside Lead and Aluminum Containers, as a Function of Distance, Derived from 1-Phase Chloroform Chemical Dosimeter Data (Wasp, Moth, Hornet, Bee, and Wasp-Prime)

	In Aluminum (rep)	In Lead (rep)	Ratio of Dose Lead/Al
Wasp	$\frac{8.09 \times 10^{9} e^{-D/240}}{D^2}$	$\frac{5.23 \times 10^{9} e^{-D/240}}{D^2}$	.65
Moth	$\frac{1.14 \times 10^{10} e^{-D/230}}{D^2}$	$\frac{4.16 \times 10^{9} e^{-D/230}}{D^2}$	.37
Hornet	$\frac{2.56 \times 10^{10} e^{D/225}}{D^2}$	$\frac{1.38 \times 10^{10} e^{-D/225}}{D^2}$	.54
Bee	$\frac{2.45 \times 10^{11} e^{-D/215}}{D^2}$	$\frac{9.88 \times 10^{10} e^{-D/215}}{D^2}$	.39
Wasp-Prime	$\frac{3.82 \times 10^{10} e^{-D/225}}{D^2}$	$\frac{1.82 \times 10^{10} e^{-D/225}}{D^2}$	.48

D = distance in yds.

[redacted]

TABLE 5.6 - Gamma Radiation Dose (in rep) inside Alumimum Stations, Versus Distance, Derived from 1/2-Phase Chemical Dosimeter Data (Wasp, Moth, Hornet, Bee, and Wasp-Prime)

	Gamma (rep)	Dose, Zero Distance (rep/Kt)
Wasp	$\frac{4.00 \times 10^9 e^{-D/300}}{D^2}$	3.3×10^9
Moth	$\frac{3.55 \times 10^9 e^{-D/325}}{D^2}$	1.4×10^9
Hornet	$\frac{6.17 \times 10^9 e^{-D/375}}{D^2}$	1.7×10^9
Bee	$\frac{2.75 \times 10^{10} e^{-D/350}}{D^2}$	3.4×10^9
Wasp-Prime	$\frac{1.23 \times 10^{10} e^{-D/345}}{D^2}$	3.4×10^9

D = distance in yds.

[redacted]

TABLE 5.7 - Formulae for Biological Dose (in rem) inside Lead and Aluminum Containers, as a Function of Distance, from Spleen-Thymus Response (Wasp, Moth, Hornet, Bee, and Wasp-Prime)

	Inside Al.	Inside Lead
Wasp	$\frac{3.4 \times 10^{10} e^{D/240}}{D^2}$	$\frac{3.5 \times 10^{10} e^{-D/210}}{D^2}$
Moth	$\frac{2.8 \times 10^{10} e^{-D/240}}{D^2}$	$\frac{1.6 \times 10^{10} e^{-D/210}}{D^2}$
Hornet	$\frac{6.2 \times 10^{10} e^{-D/240}}{D^2}$	$\frac{4.5 \times 10^{10} e^{-D/210}}{D^2}$
Bee	$\frac{3.0 \times 10^{11} e^{-D/240}}{D^2}$	$\frac{2.1 \times 10^{11} e^{-D/210}}{D^2}$
Wasp-Prime	$\frac{1.6 \times 10^{11} e^{-D/240}}{D^2}$	$\frac{1.4 \times 10^{11} e^{-D/210}}{D^2}$

D = distance in yds.

[redacted]

Fig. 2.1 Series "a" Station Consisting of 7-inch Dome Used to Expose Mice and Other Materials to Neutrons

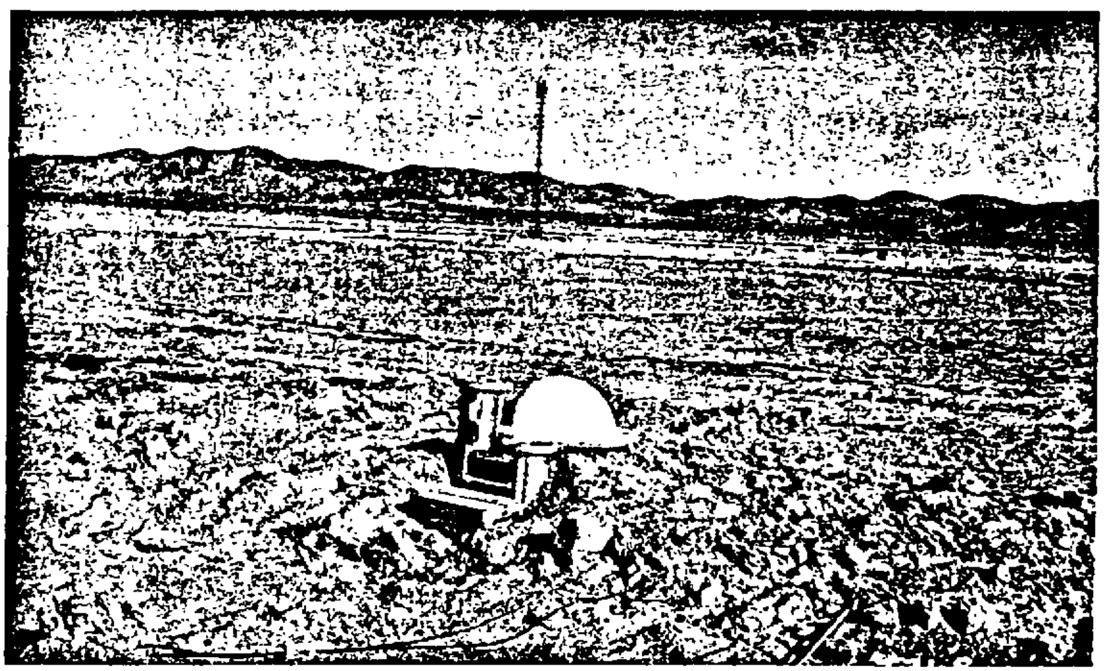

Fig. 2.2 Series "b" Station Consisting of 1/4-inch Aluminum Dome Used to Expose Mice and Other Materials to Neutrons Plus Gamma Rays

[redacted]

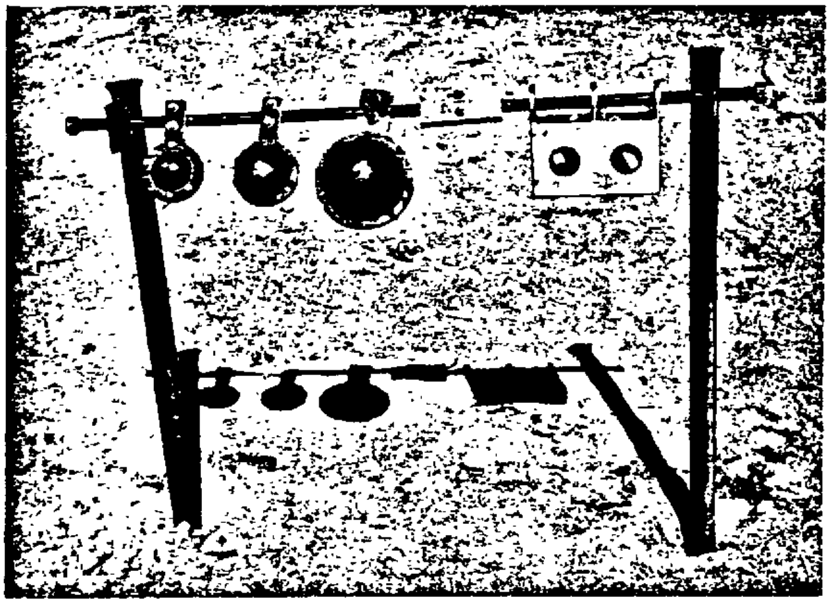

Fig. 2.3 Series "c" Station Consisting of a Goal Post Arrangement Used to Expose Threshold Detectors and Film Badges to Neutrons and Gamma Rays in Air

Fig. 2.4 Pipe Station Used in Connection with Series "c" Station for Exposure of Film Badges to Irradiation Above and Below Ground

[redacted]

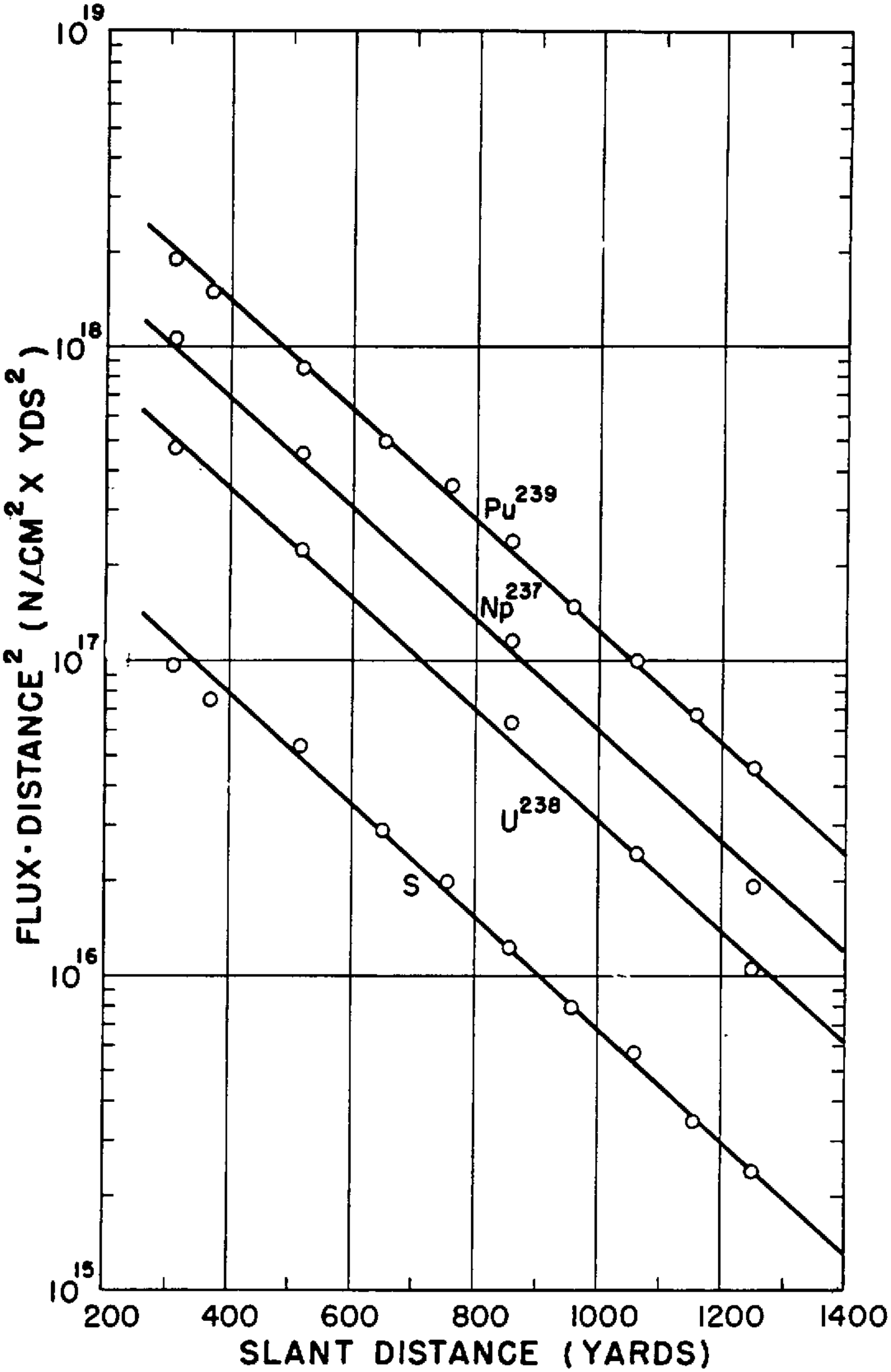

Fig. 4.1 Threshold Detector Results for Fast Neutrons in Air (Wasp)

[redacted]

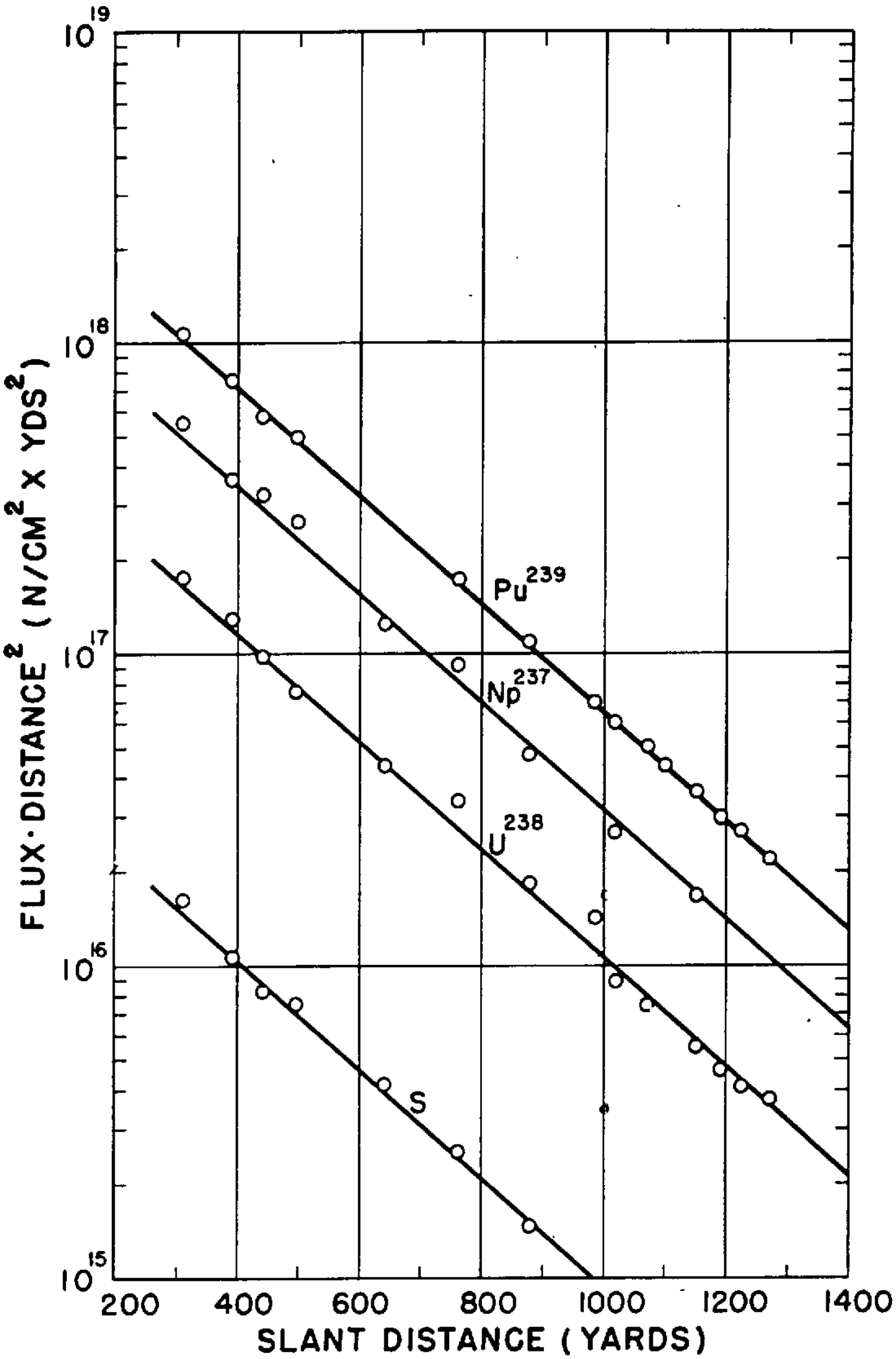

Fig. 4.2 Threshold Detector Results for Fast Neutrons in Lead (Wasp)

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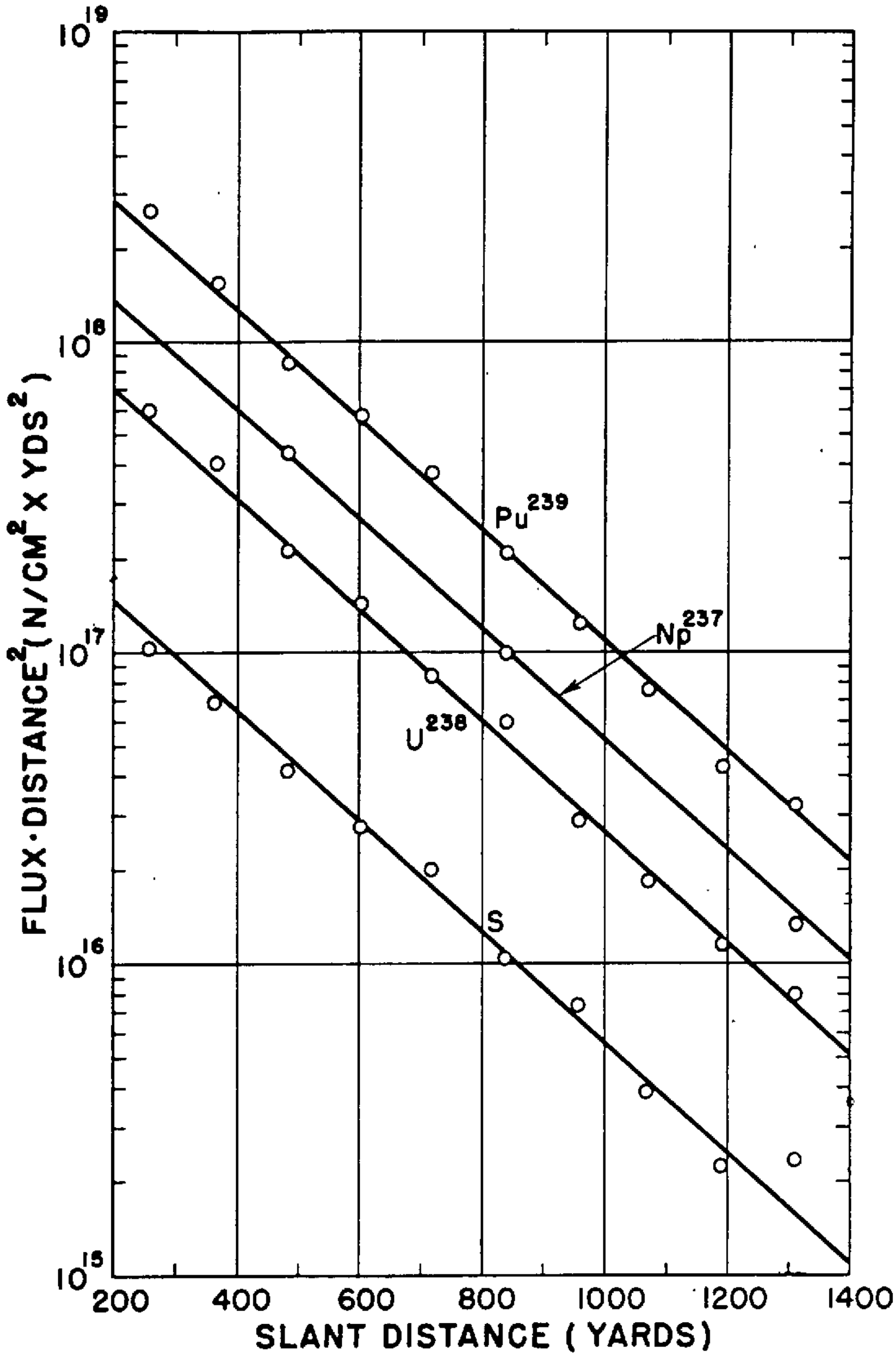

Fig. 4.3 Threshold Detector Results for Fast Neutrons in Air (Moth)

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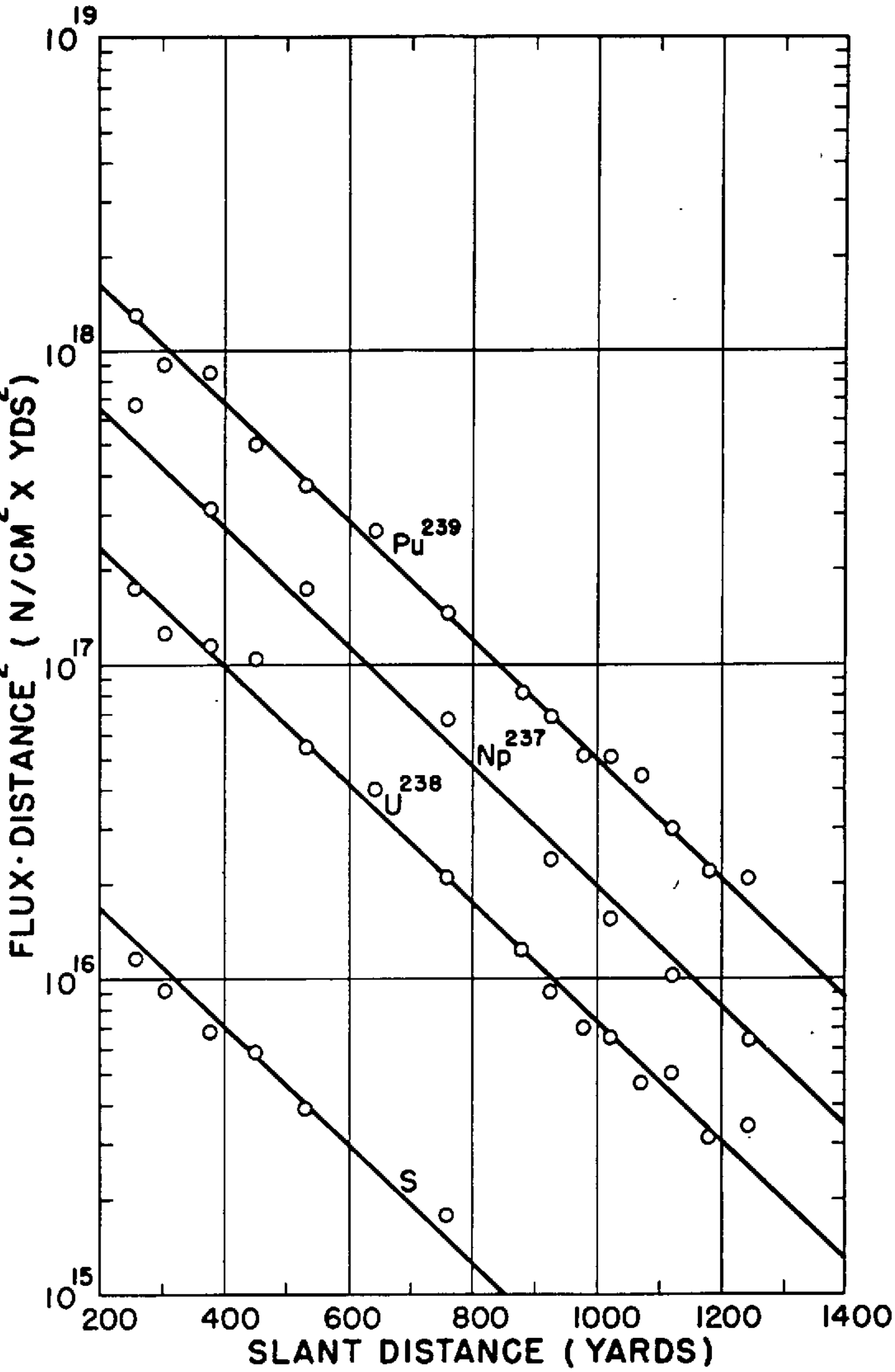

Fig. 4.4 Threshold Detector Results for Fast Neutrons in Lead (Moth)

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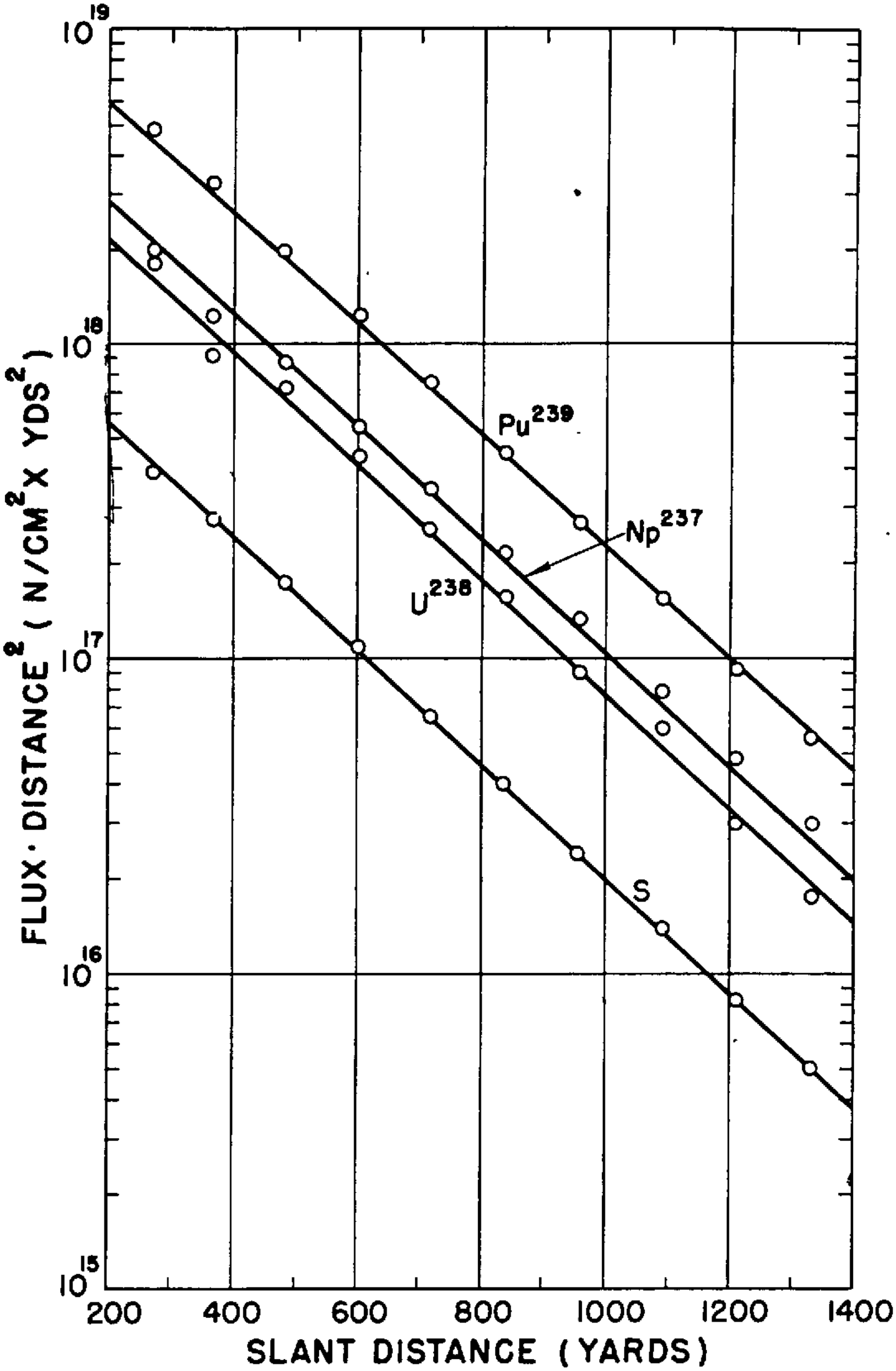

Fig. 4.5 Threshold Detector Results for Fast Neutrons in Air (Hornet)

[redacted]

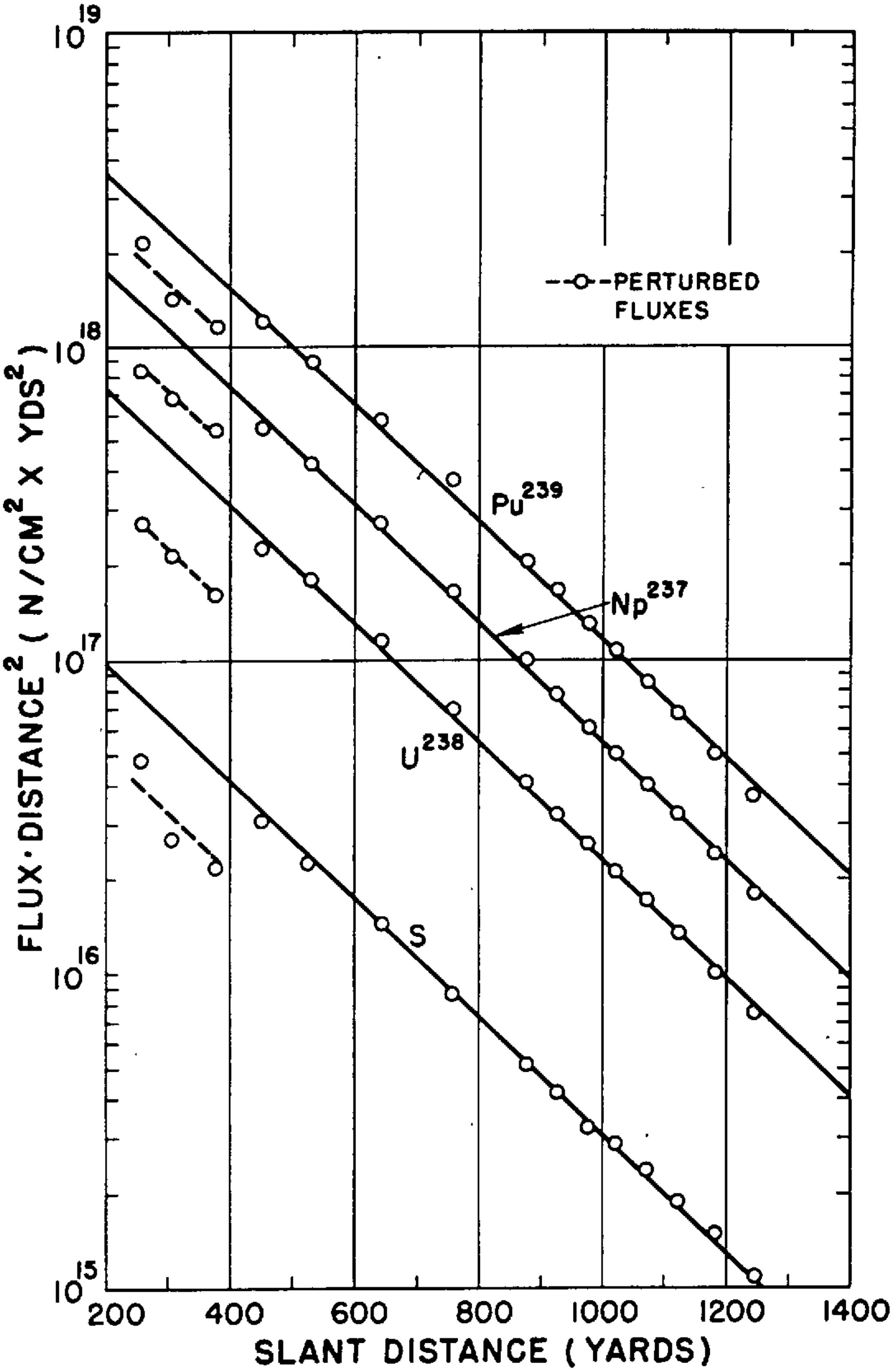

Fig. 4.6 Threshold Detector Results for Fast Neutrons in Lead (Hornet)

[redacted]

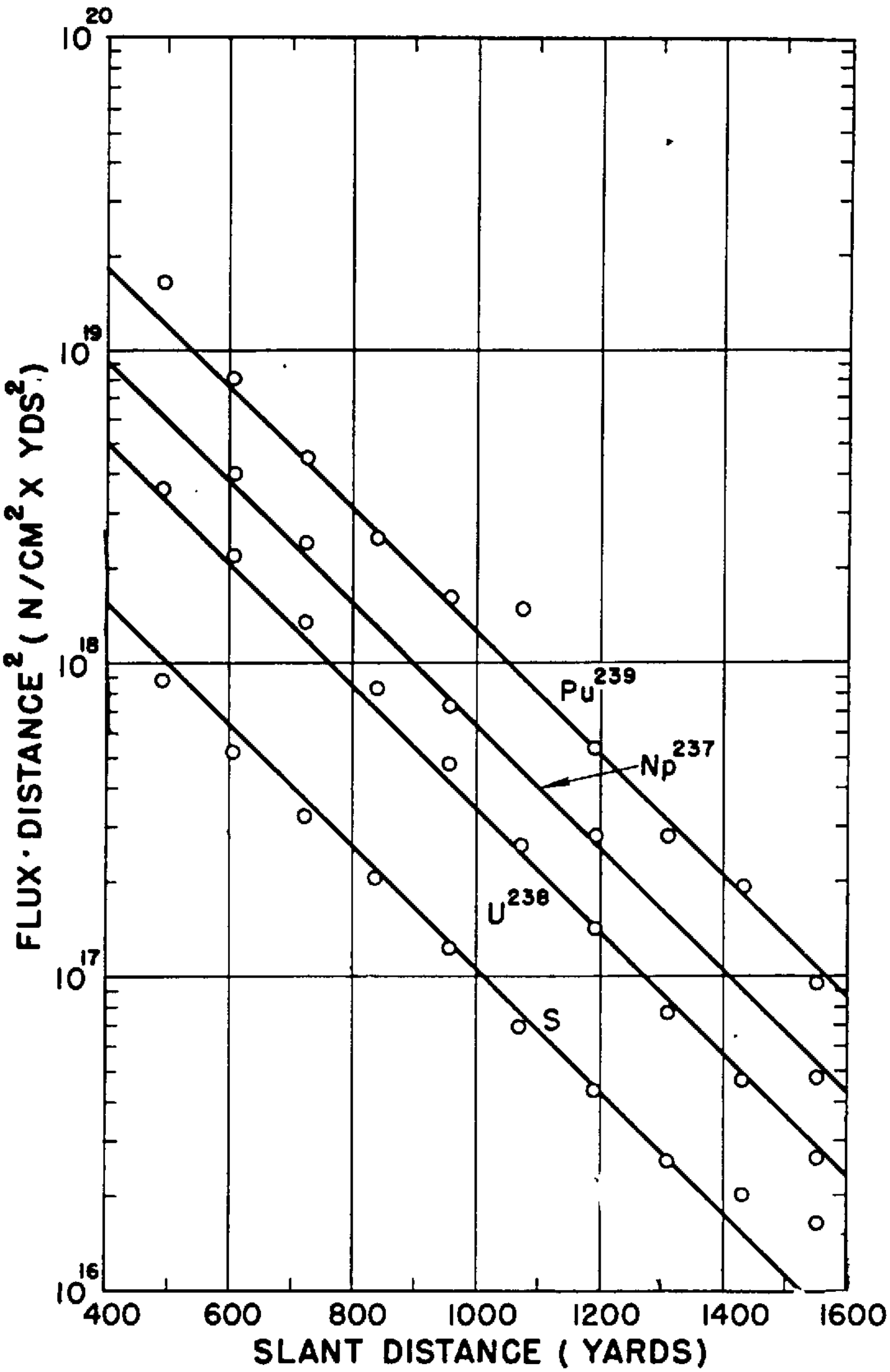

Fig. 4.7 Threshold Detector Results for Fast Neutrons in Air (Bee)

[redacted]

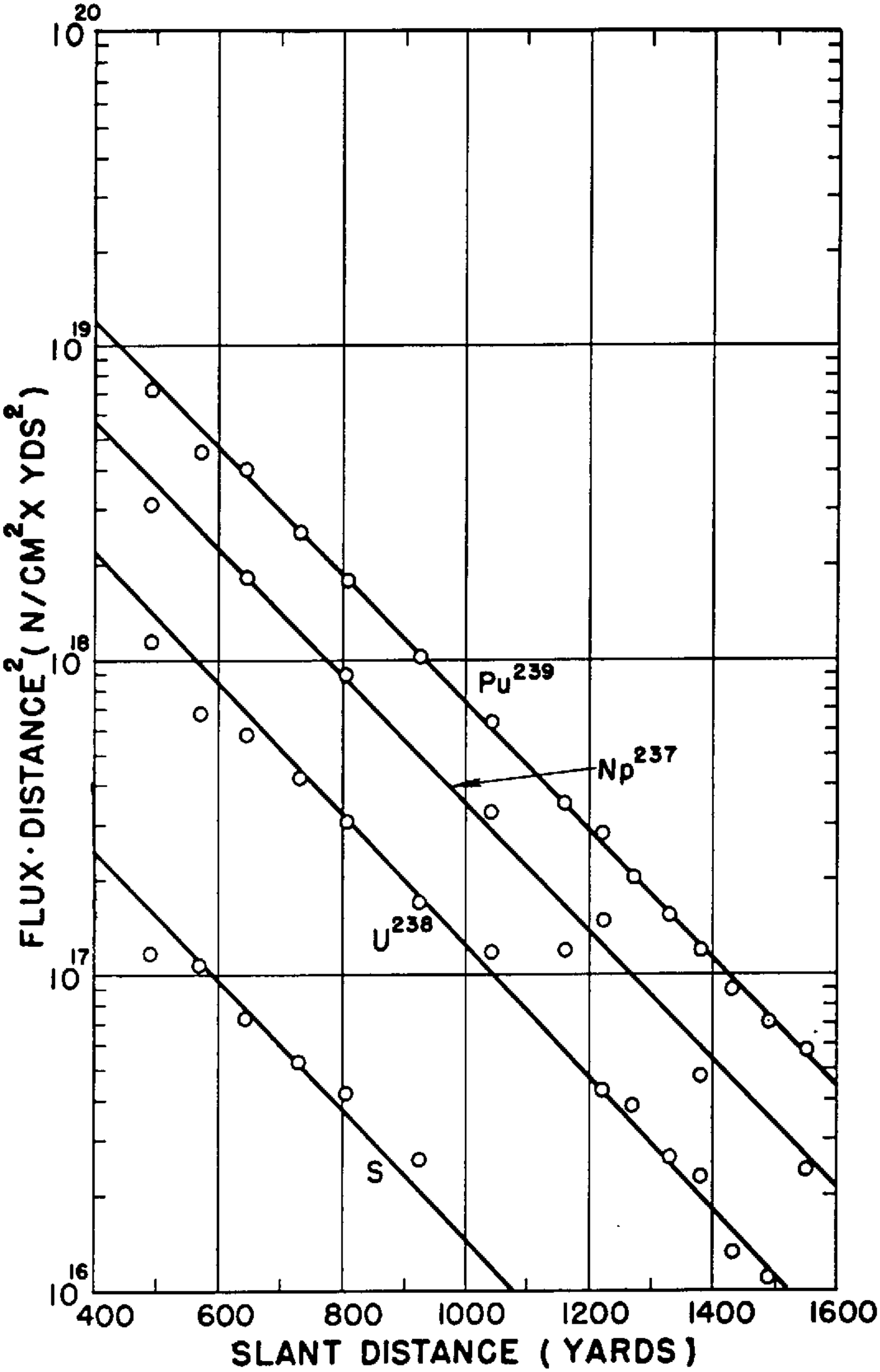

Fig. 4.8 Threshold Detector Results for Fast Neutrons in Lead (Bee)

[redacted]

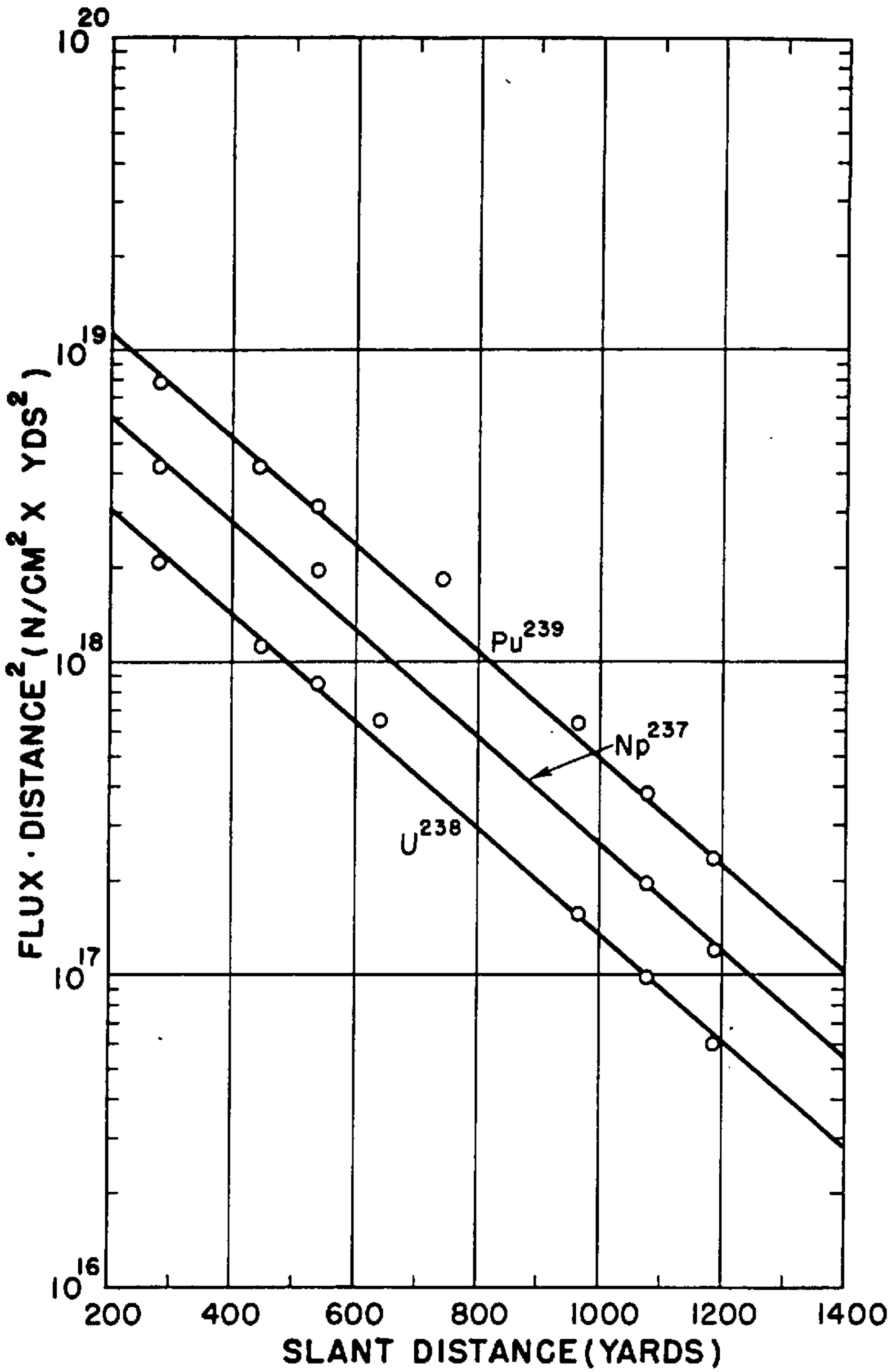

Fig. 4.9 Threshold Detector Results for Fast Neutrons in Air (Wasp-Prime)

[redacted]

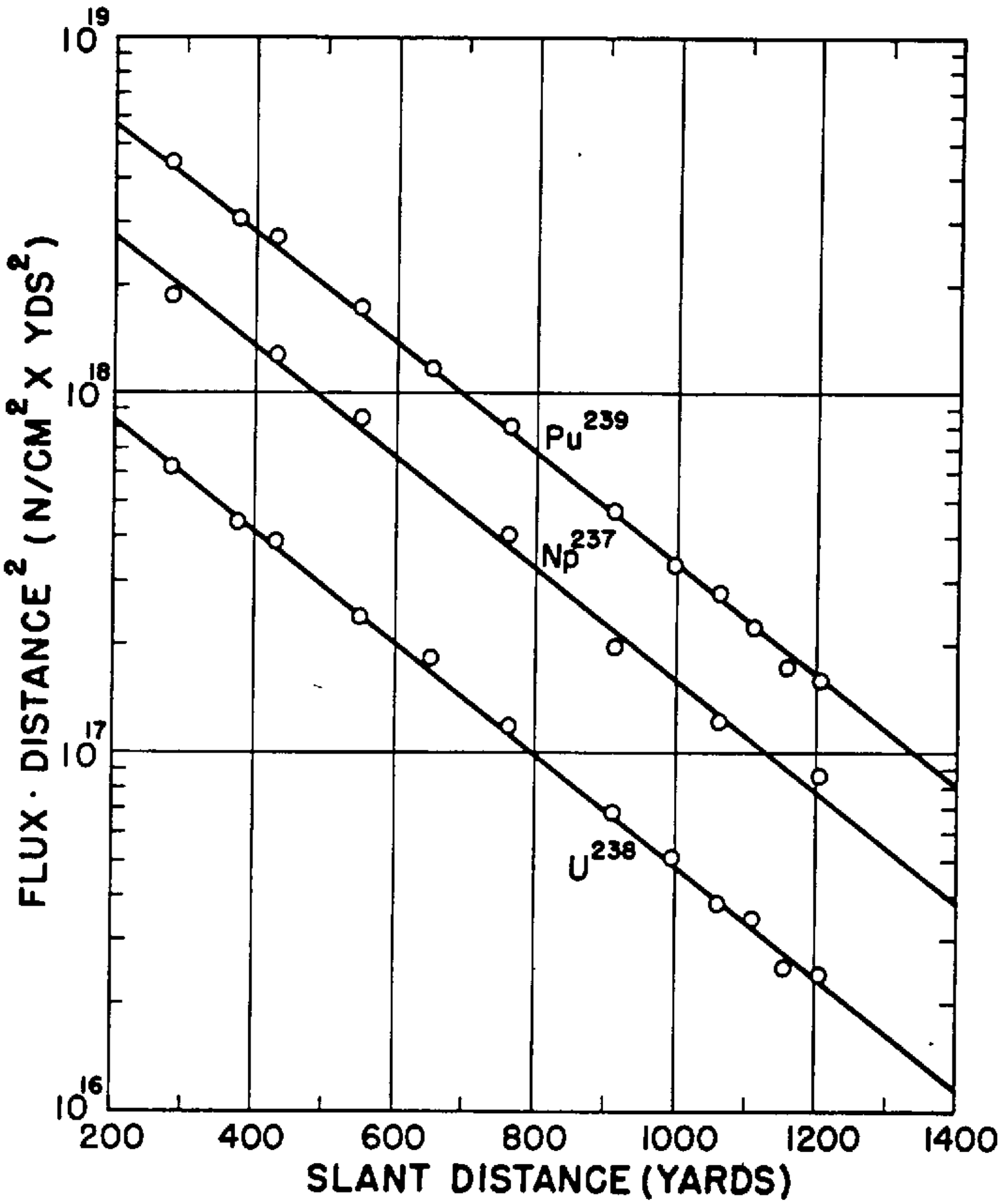

Fig. 4.10 Threshold Detector Results for Fast Neutrons in Lead (Wasp-Prime)

[redacted]

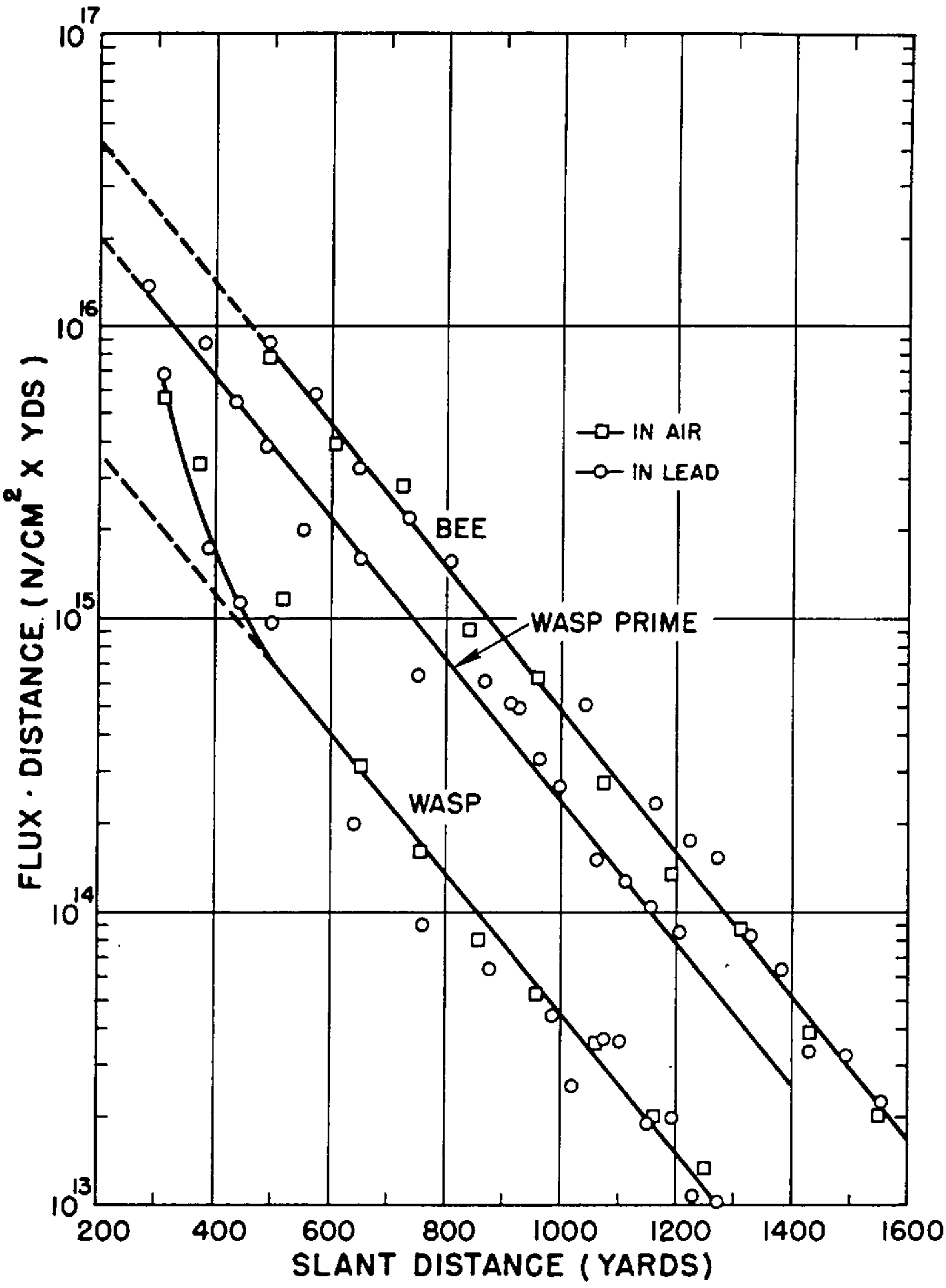

Fig. 4.11 Results of Slow Neutron Measurements inside and outside Lead (Wasp, Bee and Wasp-Prime)

[redacted]

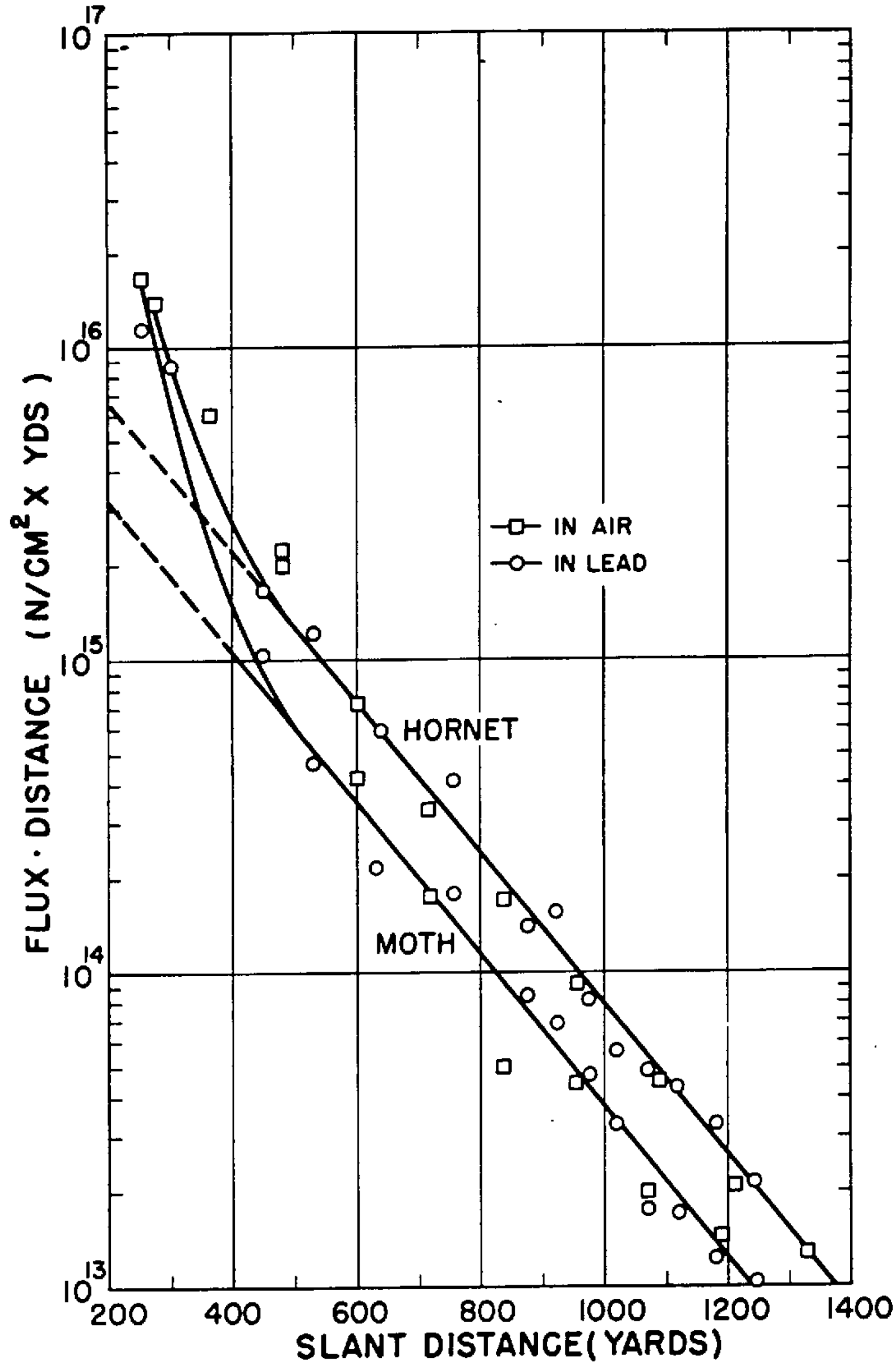

Fig. 4.12 Results of Slow Neutron Measurements inside and outside Lead (Hornet and Moth)

[redacted]

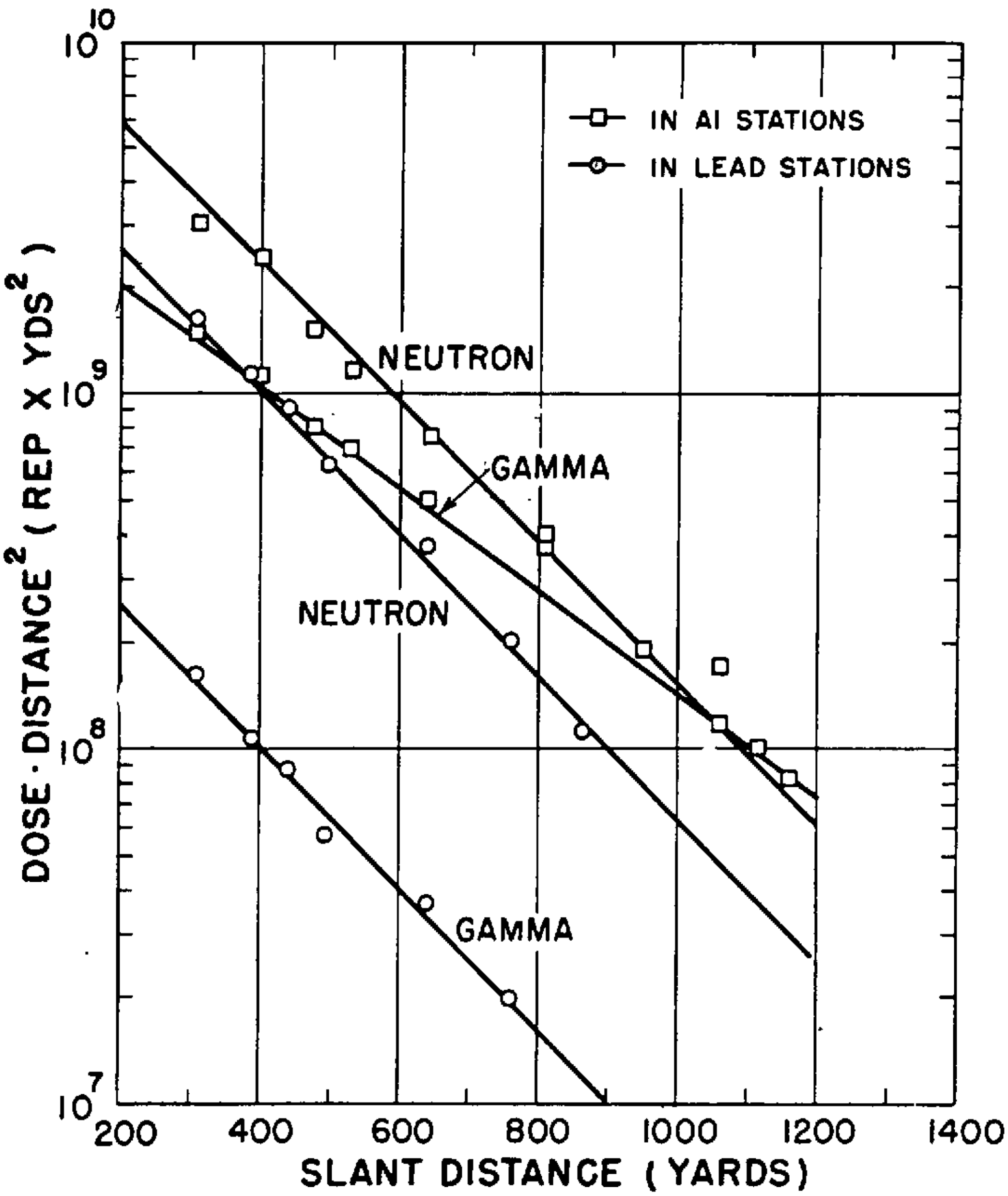

Fig. 4.13 Chemical Dosimeter Measurements of Neutron and Gamma Radiation Dose Inside Lead and Aluminum Stations (Wasp)

[redacted]

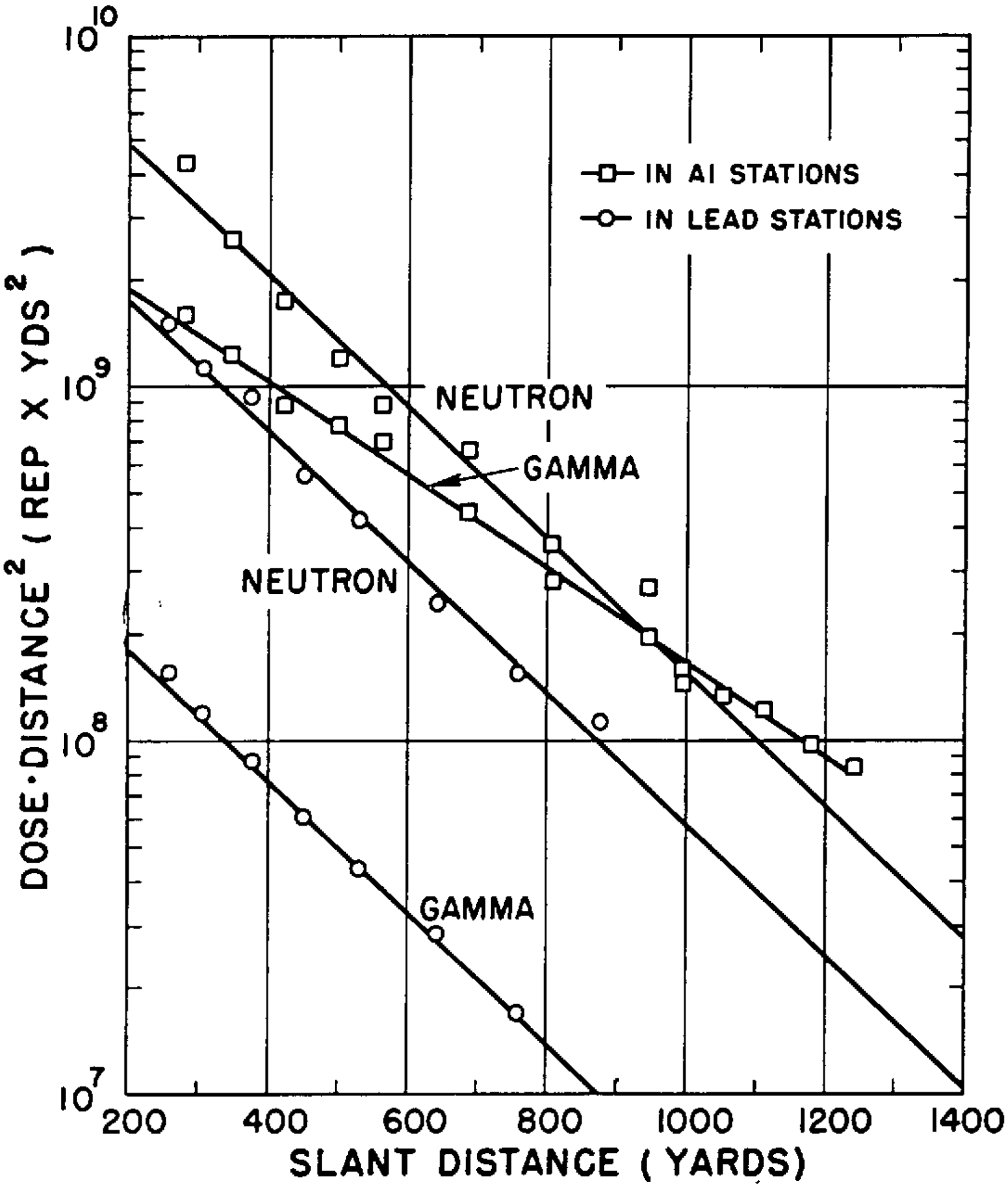

Fig. 4.14 Chemical Dosimeter Measurements of Neutron and Gamma Radiation Dose inside Lead and Aluminum Stations (Moth)

[redacted]

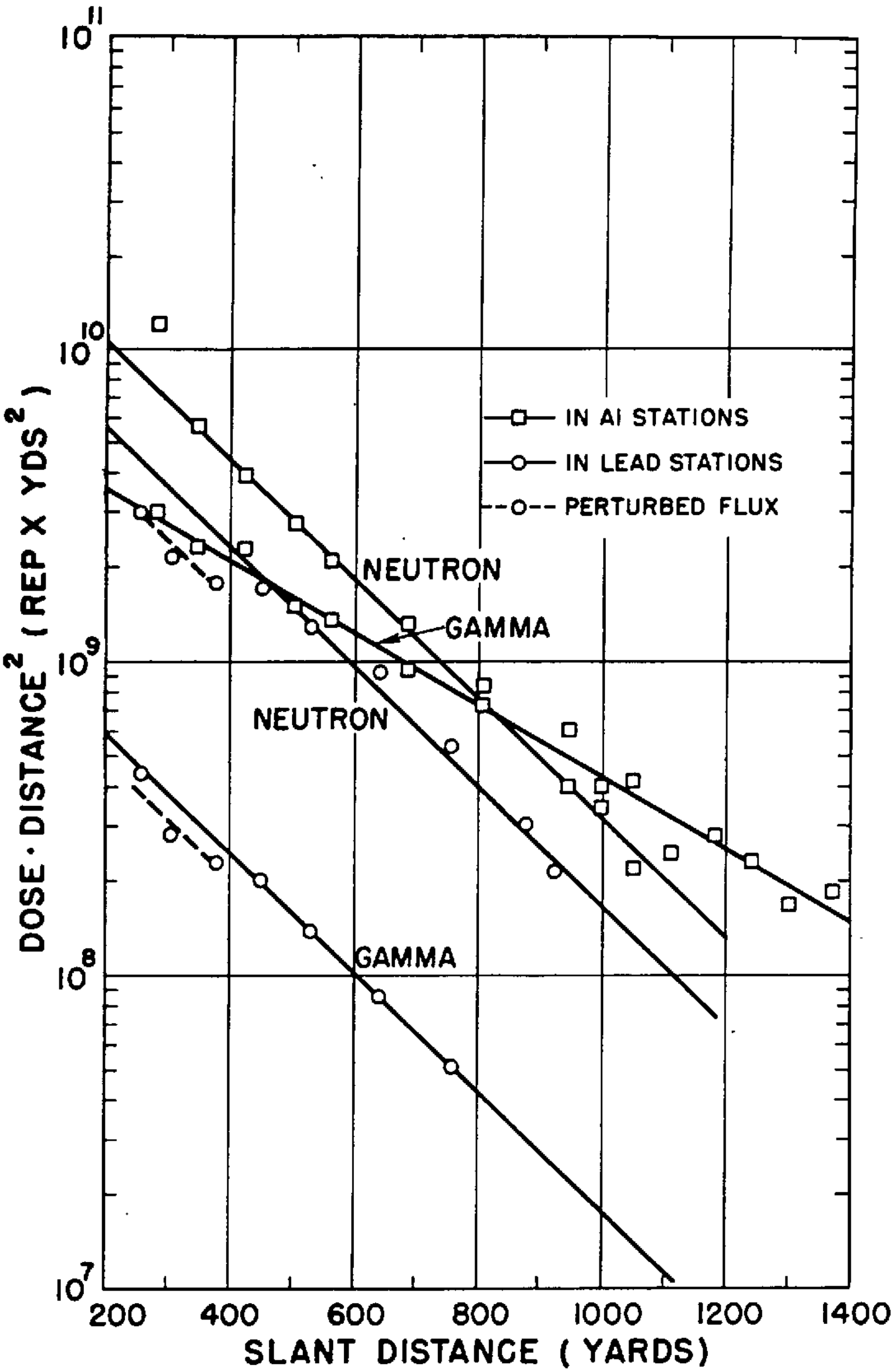

Fig. 4.15 Chemical Dosimeter Measurements of Neutron and Gamma Radiation Dose Inside Lead and Aluminum Stations (Hornet)

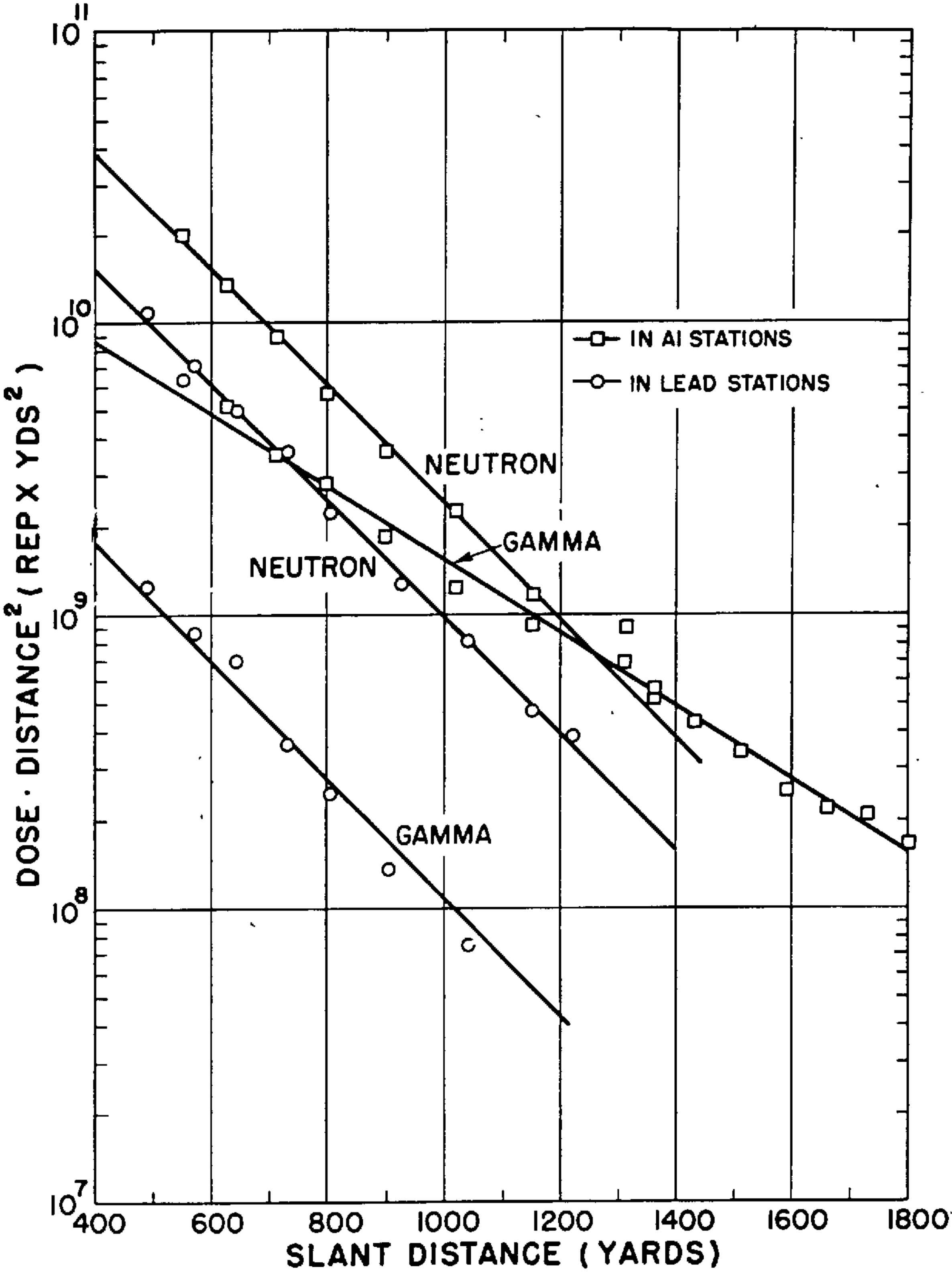

Fig. 4.16 Chemical Dosimeter Measurements of Neutron and Gamma Radiation Dose Inside Lead and Aluminum Stations (Bee)

[redacted]

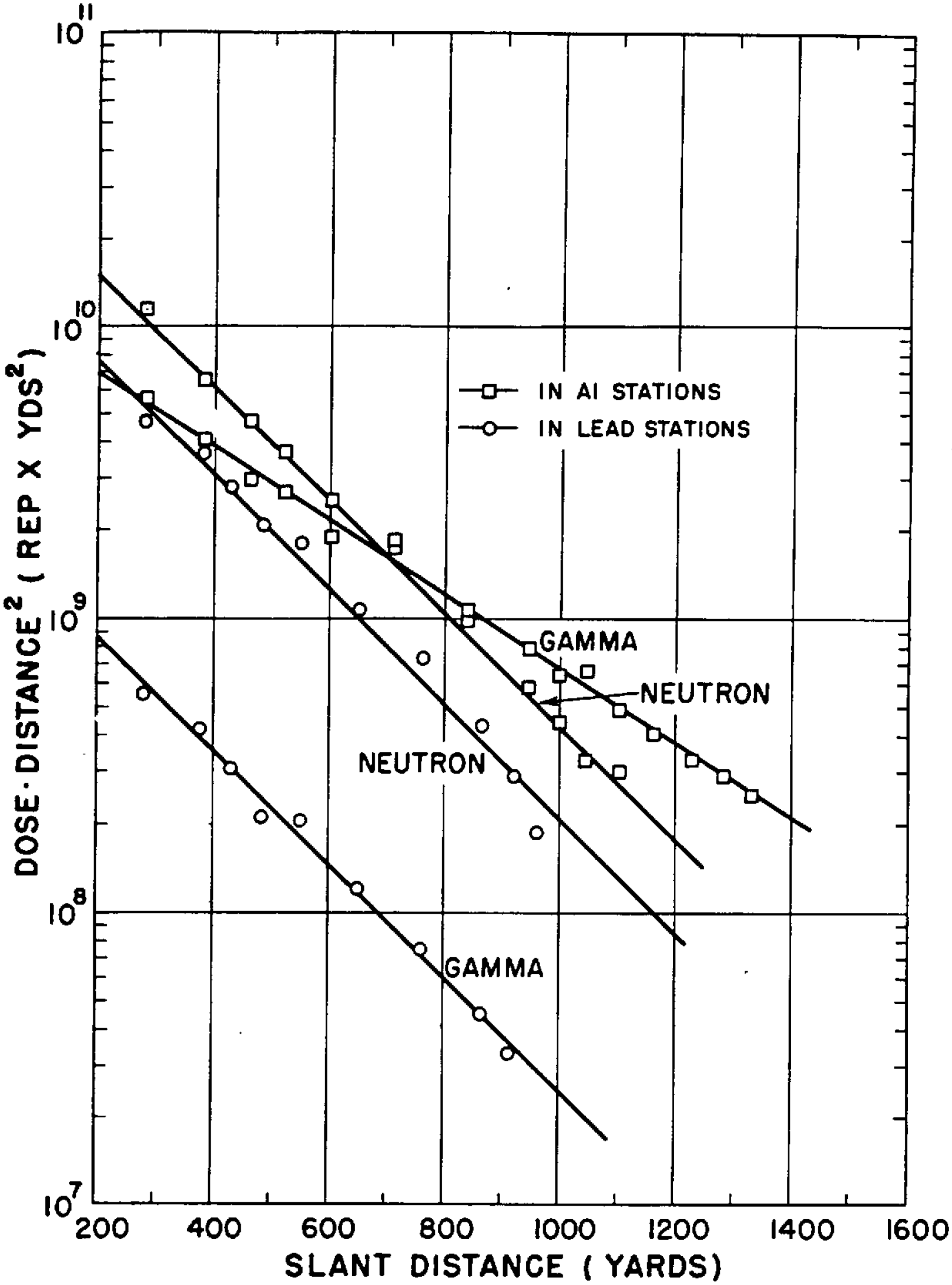

Fig. 4.17 Chemical Dosimeter Measurements of Neutron and Gamma Radiation Dose inside Lead and Aluminum Stations (Wasp-Prime)

[redacted]

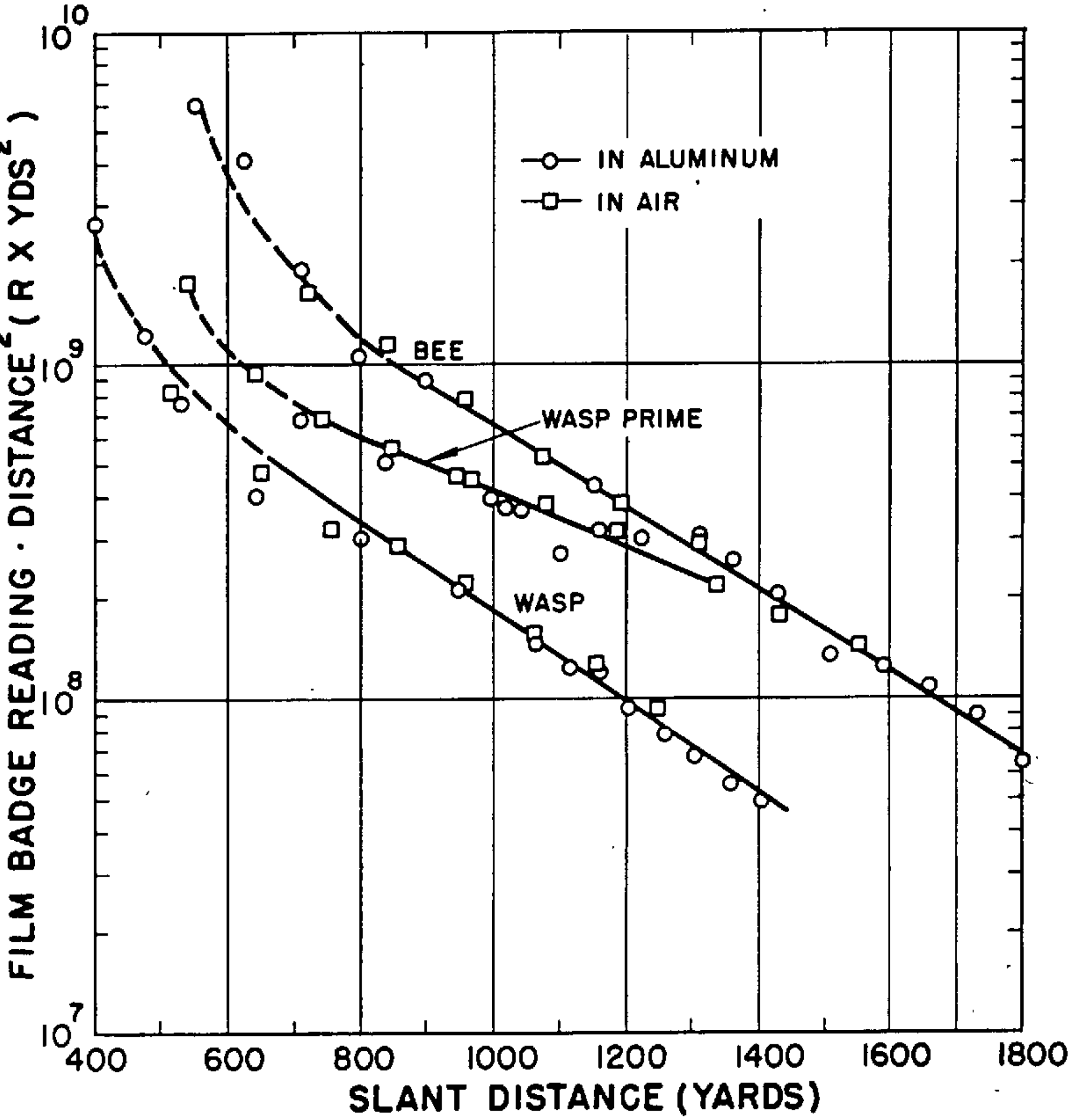

Fig. 4.18 Film Badge Readings in Aluminum Containers and in Air, as a Function of Distance (Wasp, Bee, and Wasp-Prime)

[redacted]

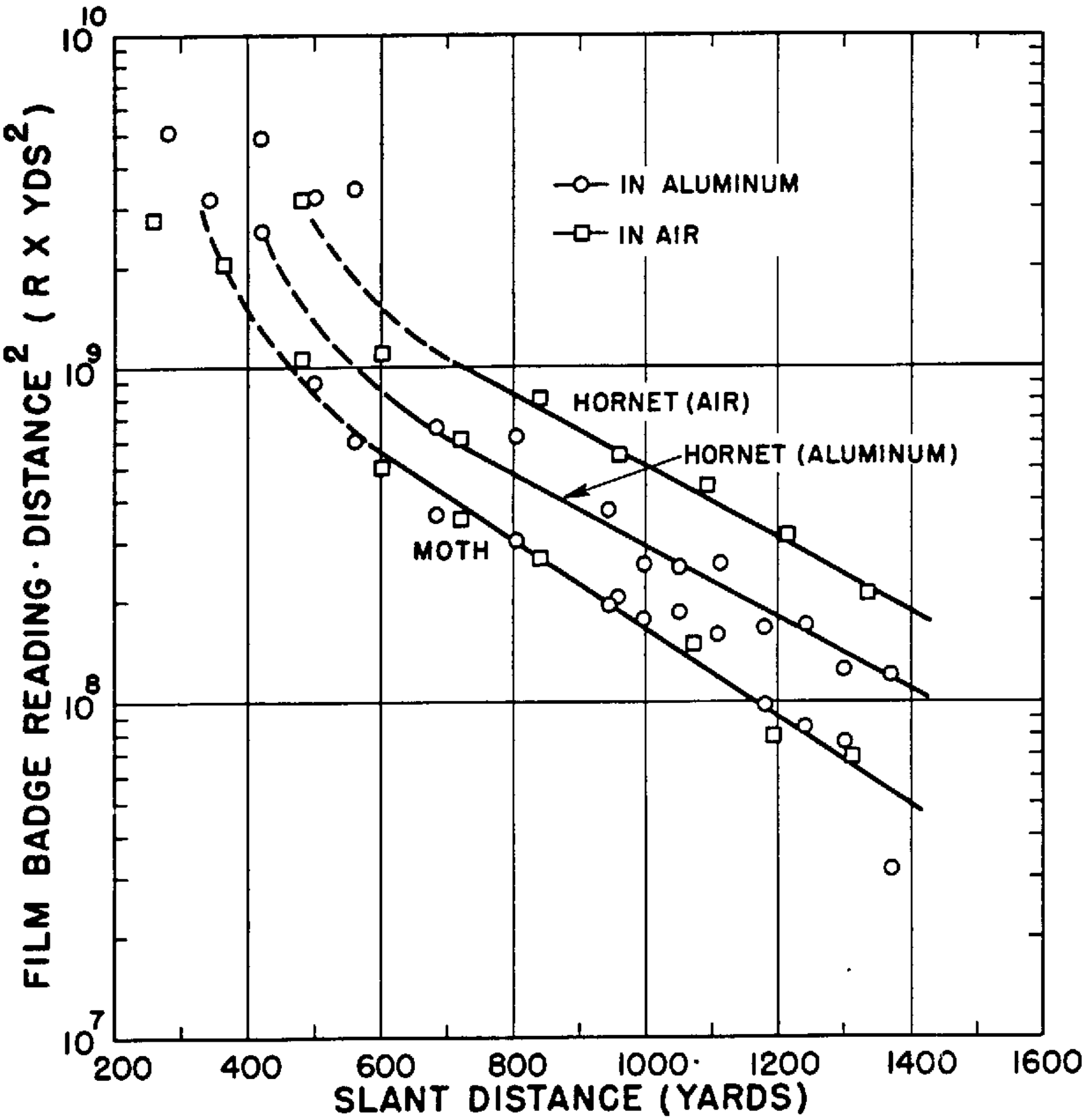

Fig. 4.19 Film Badge Readings in Aluminum Stations and in Air, as a Function of Distance (Hornet and Moth)

[redacted]

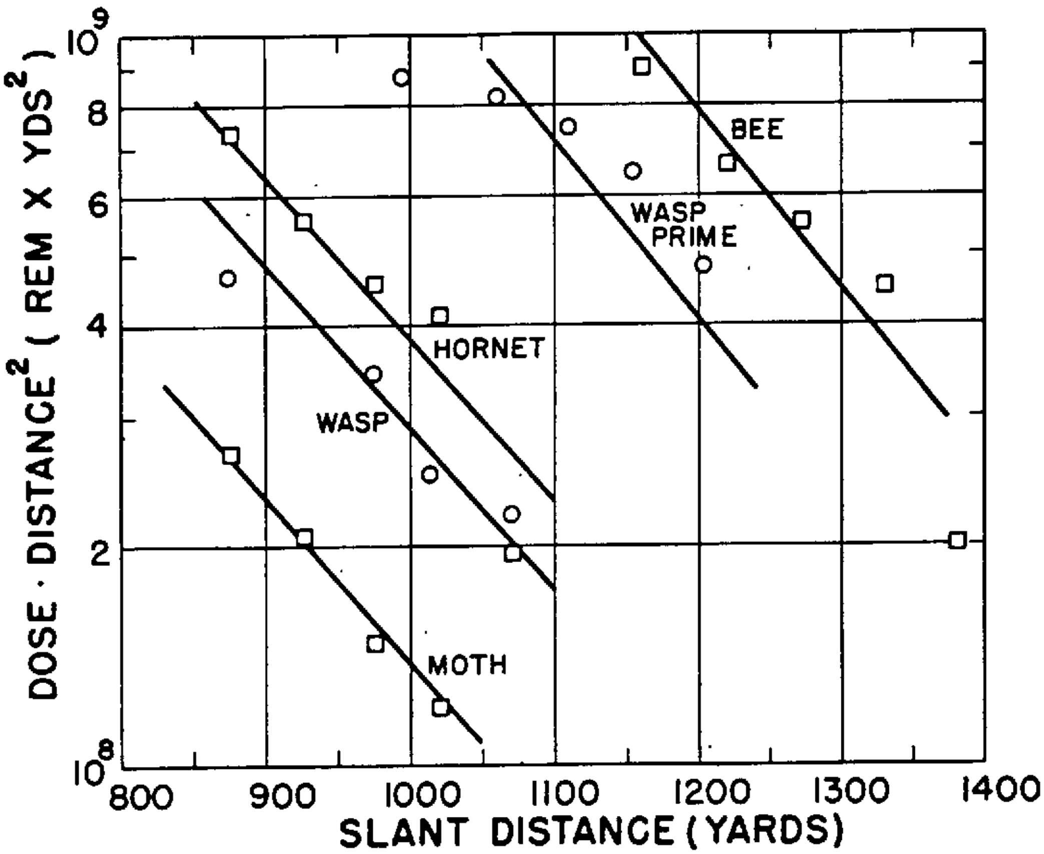

Fig. 4.20 Spleen-Thymus Measurements of Fast Neutron Dose (in rem) as a Function of Distance (Wasp, Moth, Hornet, Bee, and Wasp-Prime)

[redacted]

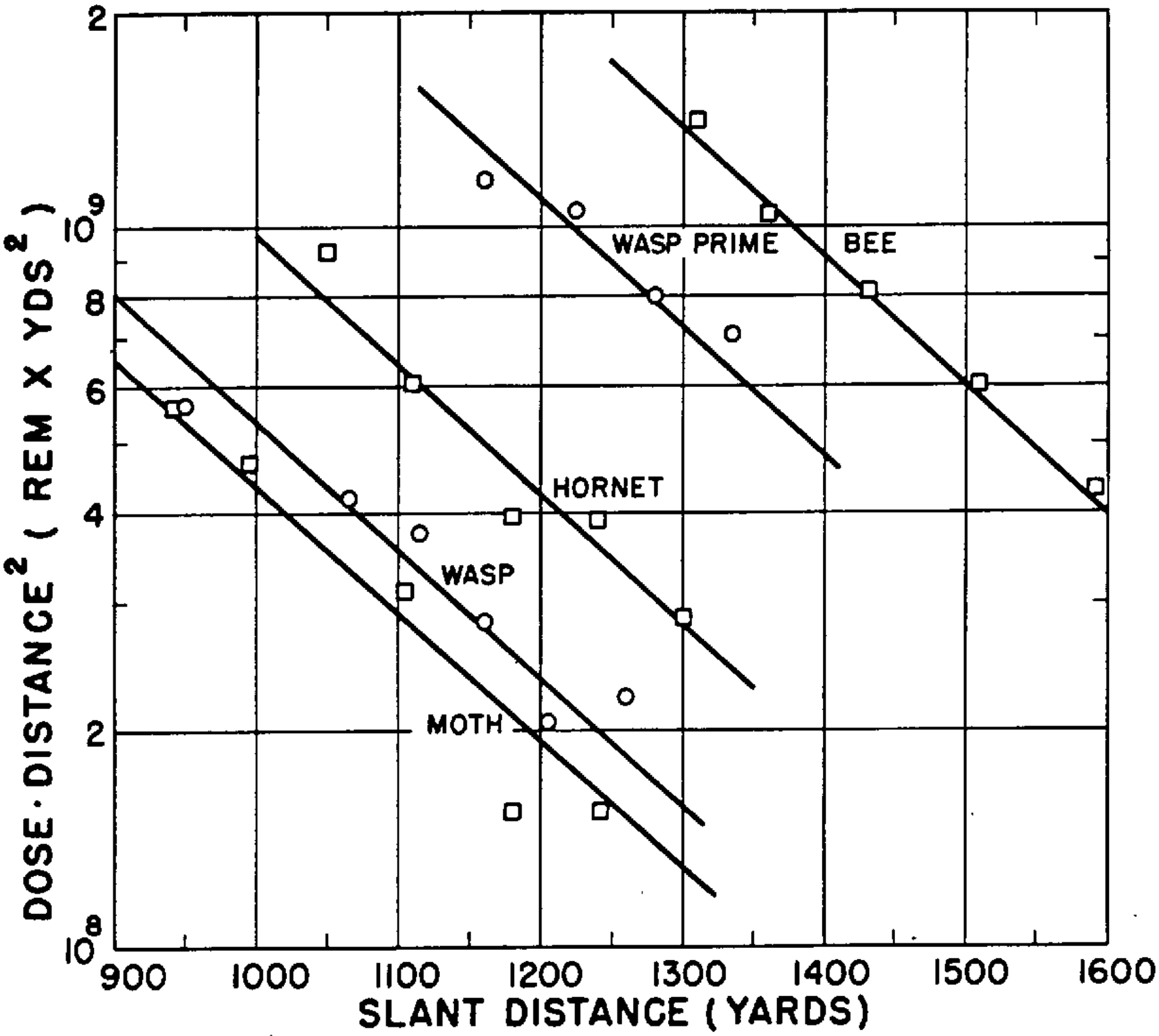

Fig. 4.21 Spleen-Thymus Measurements of Fast Neutron Plus Gamma Radiation Dose (in rem), as a Function of Distance (Wasp, Moth, Hornet, Bee, and Wasp-Prime)

[redacted]

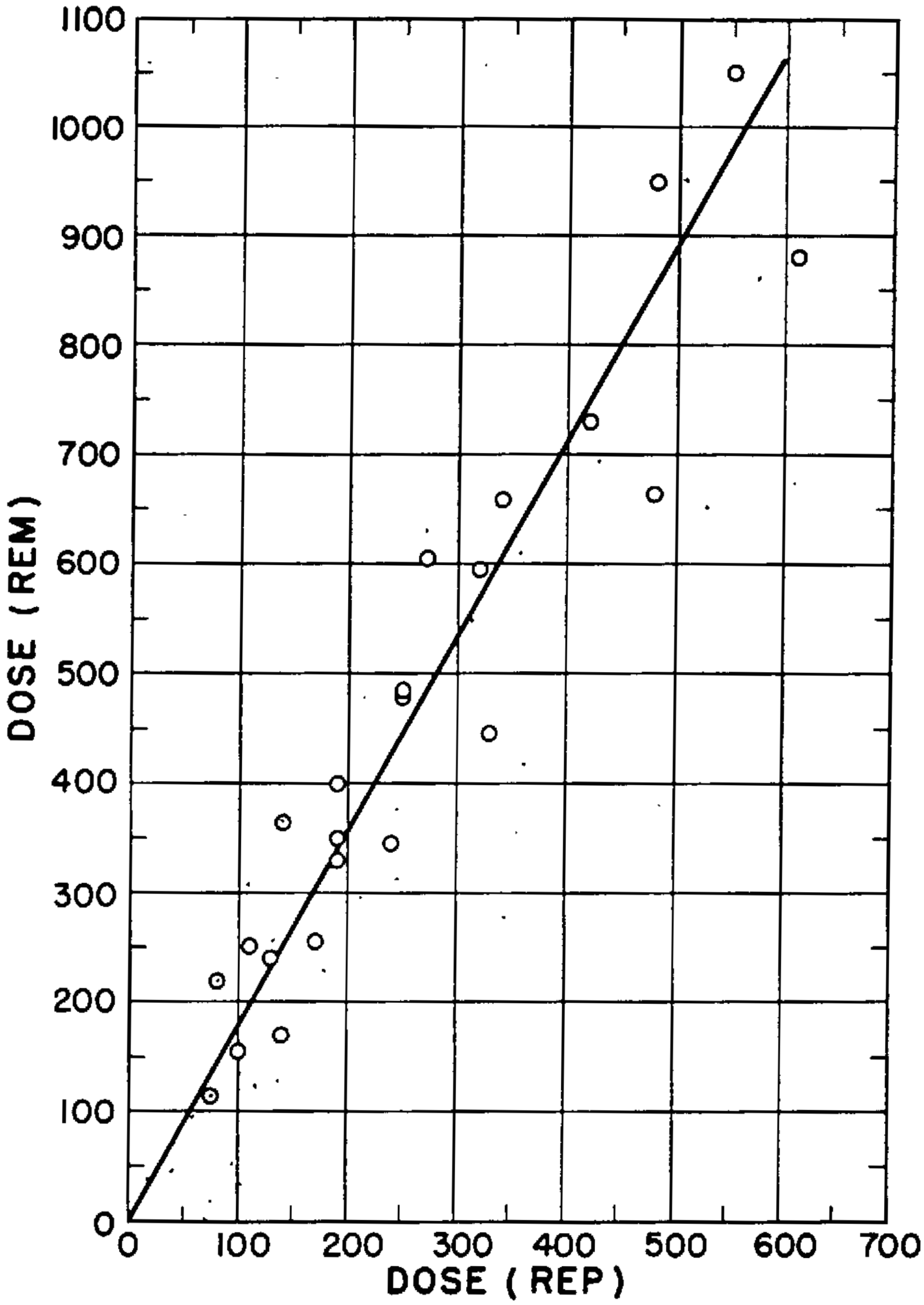

Fig. 5.1 The Relative Biological Effectiveness of Bomb Neutron Flux

[redacted]